South Florida Water Management District

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Caloosahatchee Water Management Plan Appendices

Appendix K: Assessment of Caloosahatchee Design Elements in the Restudy and the Lower East Coast Regional Water Supply Plan Using Revised Caloosahatchee Hydrology K-1

Appendix L: AFSIRS/WATBAL Water Budget Model L-1

Appendix M: Water Use and Runoff in the Caloosahatchee Basin M-1

Appendix G
CALOOSAHATCHEE BASIN INTEGRATED
SURFACE WATER/GROUND WATER MODEL

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INTRODUCTION

Caloosahatchee Basin

The Caloosahatchee Basin is located in South Florida (**Figures G-1** and **G-2**) and covers an area of approximately 1,200 square miles (mi^2) (3,100 square kilometers [km^2]). The freshwater portion of the basin encompasses the area from Lake Okeechobee upstream to the Franklin Lock (S-79) downstream, an area of approximately 1,050 mi^2 (2,720 km^2).
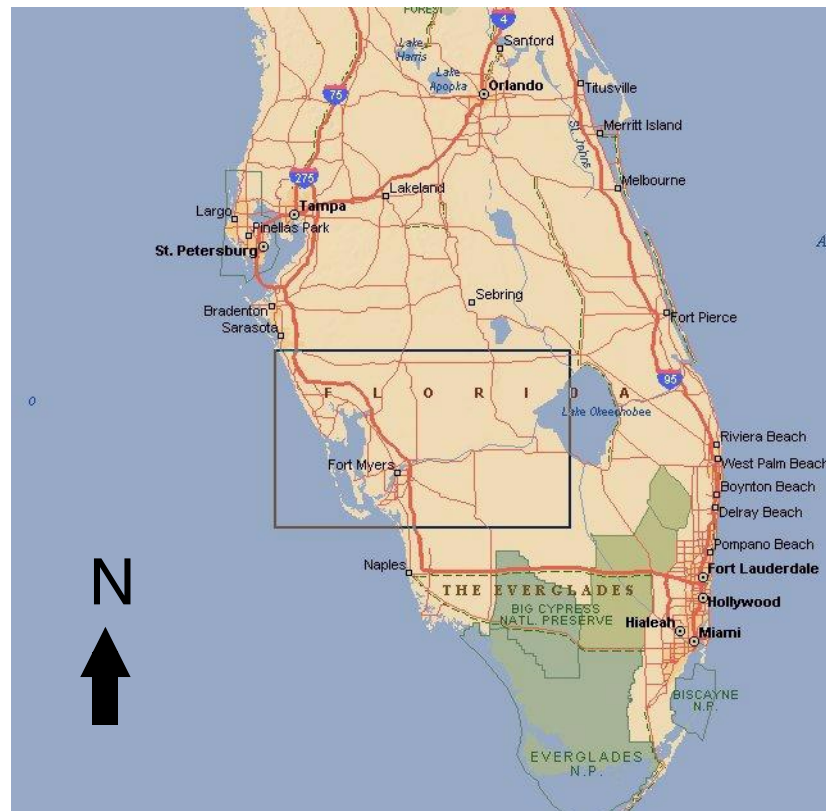
Figure G-1. Central and South Florida (approximate scale 1:1,500,000).
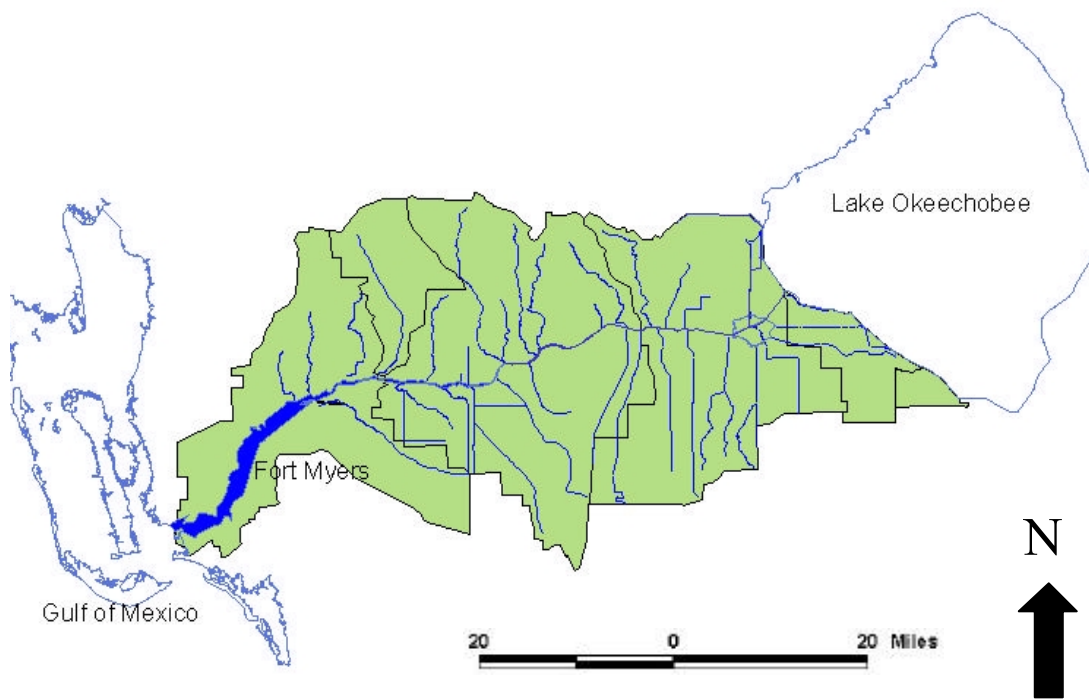
Figure G-2. The Caloosahatchee Basin.

The basin is relatively flat with little or no topographical relief. Larger depressions and sloughs with the capacity of retaining large volumes of storm water have been partially drained as part of agricultural development. A large number of wetlands and retention ponds are, however, found scattered across the basin.

The surface water flow is to a large extent controlled by the dense river network. The Caloosahatchee River (C-43 Canal) receives water from Lake Okeechobee upstream at Moore Haven Lock (S-77). Ortona Lock (S-78) approximately 16 mi (26 km) downstream, drains the eastern part of the basin. The freshwater upper part of the river is separated from the saline lower part and Franklin Lock (S-79) 43 mi (69 km) downstream of Lake Okeechobee.

The C-43 Canal passes through depressional areas at Lake Hicpochee (5,400 - 10,500 meters [m]). A number of major irrigation and drainage canals are connected to the C-43 Canal downstream from Lake Hicpochee on the southern side. The water is pumped from the C-43 Canal to maintain target water levels in the irrigation canals. Weirs are constructed to increase the water levels in each subsection of the canals. On the northern side, drainage canals and natural streams discharge (mostly unregulated) into the main C-43 Canal.

A large number of structures control the flow throughout the Caloosahatchee Basin. On the C-43 Canal, the locks at S-77, S-78, and S-79 are operated for navigational purposes and for water level control. Further upstream in tributaries, a large number of gates, weirs, and pumps control flows and water levels. The structures regulate both the drainage and irrigation water supply.

The soils in the Caloosahatchee Basin are generally coarse and sandy with a high infiltration capacity. Horizons of less permeable finer sediments are found locally especially in depression areas.

The upper aquifer system consists of shells, sand, and limestone with a relatively high hydraulic conductivity. Shallow water tables are found in most parts of the Caloosahatchee Basin. The water table response to rainfall indicates a close link between rainfall, surface water, and ground water. The Tamiami aquifer in the eastern part and the Sandstone aquifer in the western part of the basin constitute the major sources of ground water in the basin.

The Caloosahatchee Basin is characterized by a direct coupling between the surface water and ground water. Effective drainage schemes, high conductivities for the subsurface flow, and high hydraulic contact between aquifer and canals cause rapid runoff to the C-43 Canal following rainfall events. Comparison between rainfall records and measured flow at the C-43 locks show a rapid hydrologic response in water levels and flows.

Irrigation accounts for almost all of the water use in the Caloosahatchee Basin. Water for irrigation purposes is mainly pumped from irrigation canals, but a large number of ground water wells are found in parts of the area. Sugarcane, citrus, truck crops, and improved pasture are the main crops irrigated crops. During dry periods, irrigation demands are met by the release of water from Lake Okeechobee to the C-43 Canal. Water is pumped from the C-43 Canal upstream into the primary irrigation canals and eventually into minor ditches or directly onto the fields.

Background and Objectives

The *Caloosahatchee Water Management Plan* (CWMP) is part of the Lower West Coast (LWC) Water Supply Plan. The project aims at providing a plan for the following:

- Adequate supply of water for all existing and future competing uses within the Caloosahatchee Basin

- Improvements to the functions of natural systems

- Improvements of surface and ground water quality

Due to the conjunctive use of surface water and ground water in the basin and the interaction between surface water bodies and the underlying aquifers, an integrated model was chosen to include all available water resources. More specifically, the applied

integrated hydrological model (MIKE SHE) was developed in order to accomplish the following:

- Quantify the volume of water used in the basin by irrigation

- Determine the relative contribution of basin runoff, ground water seepage, and Lake Okeechobee water to the total basin water resources

- Provide a planning and management tool for the LWC Water Supply Plan, which facilitates impact analysis of various water management initiatives

Model Approach

The Calooshatchee Basin Integrated Surface/Ground Water Model (ISGM) includes the freshwater portion of the basin, which stretches from Lake Okeechobee upstream to the Franklin Lock (S-79) downstream (**Figure G-3**). The model area encompasses approximately 1,050 mi^2 (2,720 km^2).
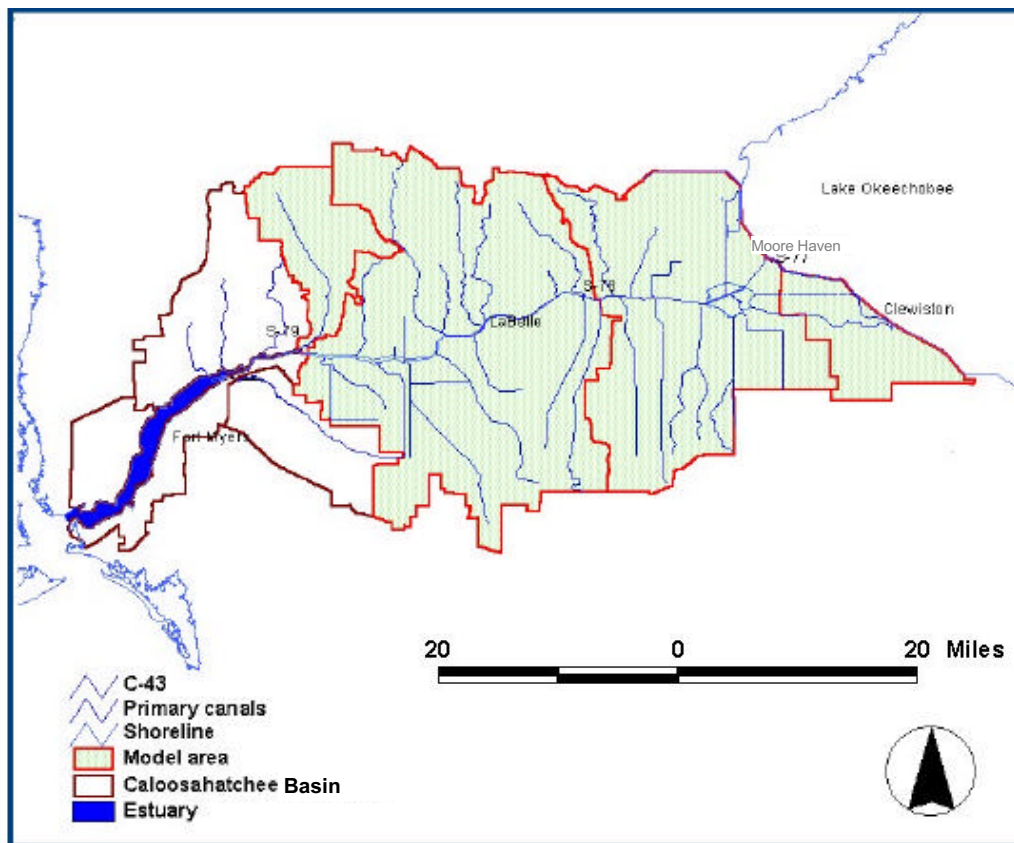
Figure G-3. The Caloosahatchee Basin and the ISGM Model Area.

The Caloosahatchee Basin may be divided into four primary subbasins based on surface topography. The eastern part of the Caloosahatchee Basin, contributes to the flow

at Ortona Lock (S-78) and the western part covering the runoff area between S-78 and Franklin Lock (S-79). Apart from these two major subbasins the S-4 Basin in the southeast and Telegraph Swamp Basin in the northwest have been included in the model. The S-4 Basin drains partly to Lake Okeechobee and partly to the eastern part of the Caloosahatchee Basin. Telegraph Creek discharges downstream of S-79 but to account for cross-boundary overland flow (which has been reported in the northeastern part of the model area during storms), the basin has been included in the model.

The basin boundaries were originally established as part of the C-43 Canal design. Land elevation changes and drainage schemes have changed the drainage patterns and boundary modifications have been made accordingly to the model (see Appendix B).

Due to the integrated nature of the surface water and ground water resources, an integrated approach was adopted. The model must have the following capabilities in simulating major flow processes within the basin:

- Overland sheetflow and depression storage

- Infiltration and storage in the unsaturated zone

- Dynamic exchange between unsaturated zone-ground water (recharge)

- Dynamic exchange between aquifers-rivers/canals (seepage)

- Ground water flow, storage and potential heads

- River/canal flow and water levels

- Evapotranspiration losses

- Effects of drainage

- Effects of irrigation water allocation

In order to cover all processes with one model, the MIKE SHE modeling system was selected. The model is an integrated and distributed, physically based, finite-difference model. MIKE SHE comprises a number of flow modules, which may be combined to describe flow within the entire land-based part of the hydrological cycle or tailored to studies focusing of areas of particular interest.

The model components for the Caloosahatchee Basin model are given in **Table G-1**.

Table G-1. Model Components Applied for Caloosahatchee Basin ISGM.

Model Component	Simulates	Fully Dynamic Coupling with	Dim	Governing Equation
MIKE SHE OL	Overland sheetflow and water depth, depression storage	MIKE SHE SZ, UZ, and MIKE11	2-D	Saint-Venants equation (kinematic wave approximation)
MIKE 11	Fully dynamic river and canal hydraulics (flow and water level)	MIKE SHE SZ, OL	1-D	Saint-Venants equation (dynamic wave approximation)
MIKE SHE UZ	Flow and water content of the unsaturated zone, infiltration and ground water recharge	MIKE SHE SZ, OL	1-D	Richardsons equation / gravitational flow (no effects of capillary potential)
MIKE SHE ET	Soil and free water surface evaporation, plant transpiration	MIKE SHE UZ, OL	-	Kristensen & Jensen / Penman-Monteith
MIKE SHE SZ	Saturated zone (ground water) flows and water levels	MIKE SHE UZ, OL and MIKE11	3-D	Boussinesqs equation
MIKE SHE IR	Irrigation demands (soil water deficit) and allocation (surface water/ ground water)	MIKE SHE SZ, MIKE 11	-	-
MIKE SHE PP	Preprocessing and postprocessing	-	-	-

The model area is discretisized into a number of computational cells for the numerical solution of the governing equations. The spatial scale of MIKE SHE may be chosen either to address regional basin issues or to do local detailed studies focusing on subbasins.

The Caloosahatchee Basin model may be characterized as a regional study implying that the purpose of the model is to simulate the water resources in an overall perspective. A finer grid resolution may be desirable to describe the basin in further detail, but the computer processing time and the density of available input data should be considered. As a compromise between detailed model output and computer capacity, a 1,500-ft (457 m) computational grid was applied. Parameters and input data are lumped to represent the average conditions within the computational cells.

The time scale of the surface water regime and the ground water regime are different. The model allows use of different time steps for calculation of river/canal flow and ground water flow. The river hydraulics model is run in 15 minute time steps, while overland flow is solved in 6 hours time steps and ground water flow calculations are solved in a daily time step.

INPUT DATA AND MODEL DEVELOPMENT

Meteorological Data

Rainfall

The rainfall distribution is highly variable in both time and space. Local thunderstorms account for considerable localized rainfall volumes. Accumulated rainfall from the stations in the basin and the surrounding areas do not show a clear geographical pattern. Total rainfall at the stations is generally determined by local weather phenomena.

Rainfall data from 16 stations (Alico, Alva Far, Corkscrew, Devil's Garden, Fort Myers, Immokalee, Keri Tower, Lake Okeechobee, LaBelle, Palmdale, Punta Gorda, S-131, S-78, S-79, South Lee County, and Whidden) have been obtained. The data were converted into the MIKE SHE time series format. From the 16 stations, nine stations were selected by SFWMD to represent the rainfall input in the model area. The measured time series were gap-filled by transferring values from neighboring stations. The rainfall input for the model was spatially distributed according to Thiessen polygons (**Figure G-4**).
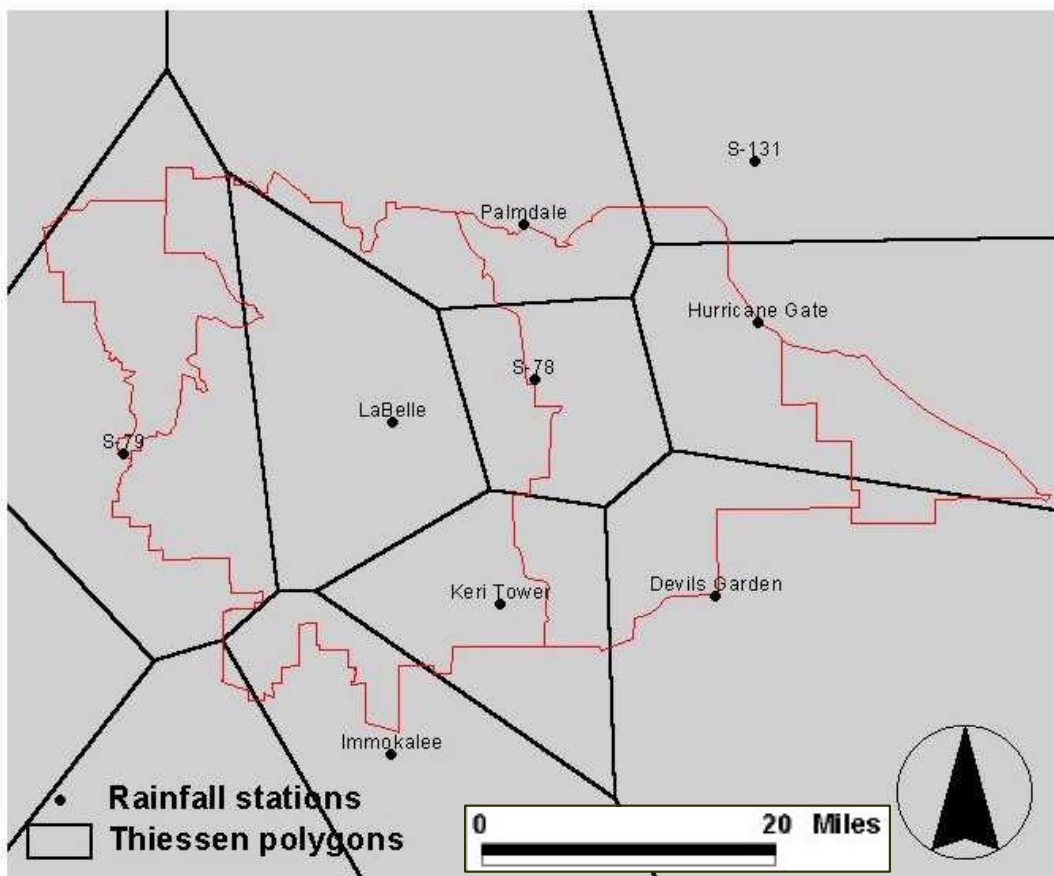
Figure G-4. Rainfall Distributed by Thiessen Polygons.

The input rainfall data are daily values (converted into the general MIKE SHE input unit - mm/h). Weight factors are calculated as the Thiessen polygon area associated with each rainfall station divided by the catchment area for S-78 and S-79. Devil's Garden, Hurricane Gate, Palmdale, S-78, and Keri Tower are the dominant stations with respect to total rainfall input to the model area (**Table G-2**). The weight factors are calculated as the area for which a specific rainfall time series is applied, divided by the subbasin area at S-78, or the entire model area at S-79.

Table G-2. Rainfall Area Weight Factors for the Caloosahatchee Basin Model.

Station	Time Series Record Number	Area Weight Factors at S-78 (percent)	Area Weight Factors at S-79 (percent)
Devil's Garden	2	23.3	9.3
Hurricane Gate	4	37.8	15.2
LaBelle	5	0.0	21.1
Palmdale	6	10.7	8.4
S-131	8	2.0	0.8
S-78	9	18.3	11.8
S-79	10	0.0	19.2
Immokalee	11	0.0	3.0
Keri Tower	12	7.9	11.2
Total		100.0	100.0

The total rainfall can be calculated from the measured rainfall and the area weight factors (**Tables G-3** and **G-4**). The total rainfall is calculated by accumulating rainfall contributions for the individual rainfall stations.

Table G-3. Monthly Rainfall in the ISGM Model at S-78 (inches), 1980-1996.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1980	3.4	1.5	1.7	4.7	2.5	2.7	6.9	5.9	5.4	1.2	3.1	0.7	39.5
1981	0.8	1.7	1.5	0.3	2.3	5.9	4.2	9.9	3.6	0.9	1.9	0.2	33.3
1982	0.6	2.4	5.0	3.0	10.0	12.9	9.7	4.6	6.1	4.2	0.5	1.0	60.1
1983	4.2	9.3	5.2	1.8	0.8	8.9	4.5	6.6	5.1	4.4	2.1	3.2	56.0
1984	0.3	3.4	5.1	2.9	7.0	6.1	9.7	5.0	4.7	0.5	2.9	0.1	47.8
1985	0.4	0.4	1.6	5.5	2.0	6.2	5.3	4.7	7.3	2.1	1.0	2.1	38.4
1986	1.9	1.0	5.6	0.2	1.6	11.6	4.6	9.1	4.2	5.6	0.4	2.8	48.7
1987	1.6	2.0	6.6	0.4	2.4	3.5	5.4	3.2	8.5	5.4	9.5	0.4	48.9
1988	2.2	2.5	3.6	1.0	1.6	4.0	8.5	9.4	1.4	0.7	5.1	0.7	40.8
1989	1.4	0.2	3.7	4.1	2.0	7.3	7.4	5.1	7.1	2.9	0.3	2.2	43.8
1990	0.8	2.7	0.9	2.5	3.1	5.2	8.2	11.7	3.1	2.9	0.8	0.2	42.0
1991	6.0	1.1	3.2	3.5	7.5	7.9	9.7	6.9	3.5	4.3	1.9	0.2	55.8
1992	1.6	3.7	3.2	2.3	1.3	19.3	4.1	8.7	3.2	0.8	1.7	0.7	50.5
1993	5.6	1.9	2.8	2.1	2.2	4.4	5.5	5.9	6.6	6.1	1.1	1.1	45.3
1994	3.5	2.6	2.5	3.2	4.1	6.2	5.7	5.5	10.6	3.6	3.4	4.9	55.8
1995	3.5	2.3	4.0	3.4	2.0	8.5	12.8	9.2	5.4	10.2	0.3	0.5	62.0

**Table G-4.** Monthly Rainfall in the ISGM Model at S-79 (inches), 1980-1996.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1980	2.7	1.5	1.4	4.0	3.2	2.2	7.1	7.2	4.8	1.3	3.3	0.6	39.5
1981	0.8	1.8	1.5	0.2	1.9	6.5	5.4	11.4	4.1	0.5	1.5	0.3	36.0
1982	0.8	1.7	4.4	3.2	9.4	12.7	8.1	5.3	7.0	3.9	0.4	0.8	57.8
1983	3.9	10.3	6.3	1.7	0.7	11.2	5.0	7.6	5.7	4.7	2.3	3.7	63.2
1984	0.3	3.2	4.8	2.5	7.0	7.0	10.5	5.1	5.0	0.6	3.1	0.2	49.1
1985	0.5	0.4	1.7	4.3	2.1	7.2	5.8	7.3	7.6	2.3	1.3	1.4	42.0
1986	2.0	1.2	4.5	0.3	1.8	11.2	5.6	8.7	4.7	4.9	0.4	3.9	49.2
1987	1.6	2.5	7.5	0.3	3.4	4.9	8.0	4.6	7.3	5.9	7.9	0.5	54.4
1988	2.2	2.4	3.9	1.8	2.6	4.0	8.2	12.3	2.0	0.7	4.9	0.8	45.7
1989	1.2	0.4	3.5	3.8	1.2	9.5	8.0	8.6	6.3	3.5	0.4	2.0	48.4
1990	0.6	3.1	1.1	2.8	3.2	6.2	7.7	11.3	3.4	3.0	0.7	0.2	43.4
1991	6.1	1.2	2.2	3.4	8.2	8.8	10.1	7.8	5.5	3.9	1.7	0.2	59.1
1992	2.0	4.1	3.3	3.3	1.2	19.5	5.3	9.2	4.3	1.0	2.1	0.7	56.0
1993	6.1	2.0	3.2	2.1	2.2	5.6	6.9	7.0	7.2	6.3	0.8	0.9	50.3
1994	3.1	2.4	2.1	3.3	3.3	6.3	5.3	7.3	9.8	3.9	3.1	4.2	54.1
1995	3.6	2.1	2.7	3.4	1.7	10.6	14.8	9.3	6.0	11.0	0.3	0.5	66.0

The average rainfall for S-79 is 51 inches for the year (for the period of record 1980 - 1995) and slightly lower (48 inches for the year) for the eastern part of the basin at S-78, for the same period of record. The driest year for the period of record was 1981 with 36 inches for the year. The wettest year for the period of record was 1995 with 66 inches for the year. The highest rainfall amounts fall during the months of June through August. The lowest rainfall amounts fall during the months of December through April.

Evapotranspiration

The model simulates the actual evapotranspiration rate. It is calculated at each time step as a percentage of the potential evapotranspiration rate. Measured time series of potential evapotranspiration rates must thus be specified as part of the model input. Two sets of potential evapotranspiration data exist for the Caloosahatchee Basin: measured pan evaporation data and Penmann estimates based on meteorological data (solar radiation, temperature, humidity, and wind speeds). These data are displayed in **Figures G-5** and **G-6**.

The data are primarily used to simulate soil or free water surface evaporation and plant transpiration. Consequently, a crop vegetation specific potential evapotranspiration rate is needed (see Land Use and Evapotranspiration). The Penmann data are considered to be the best suited data, and data from three stations (LaBelle, Fort Myers, and Moore Haven) have been applied.
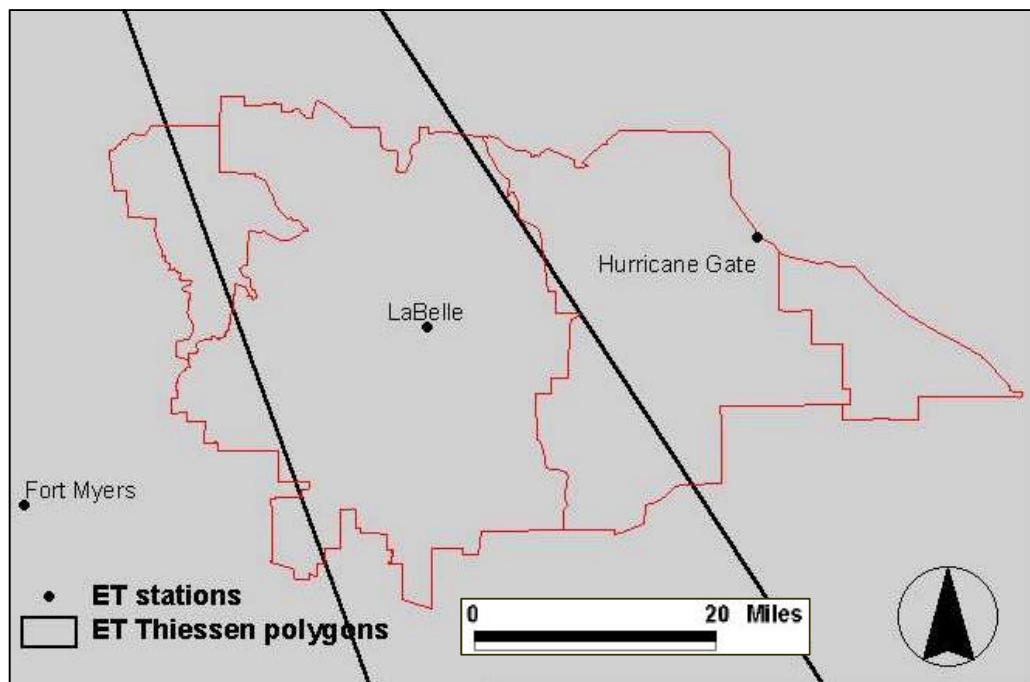
Figure G-5. Distribution of Potential Evapotranspiration Rates by Thiessen Polygons.
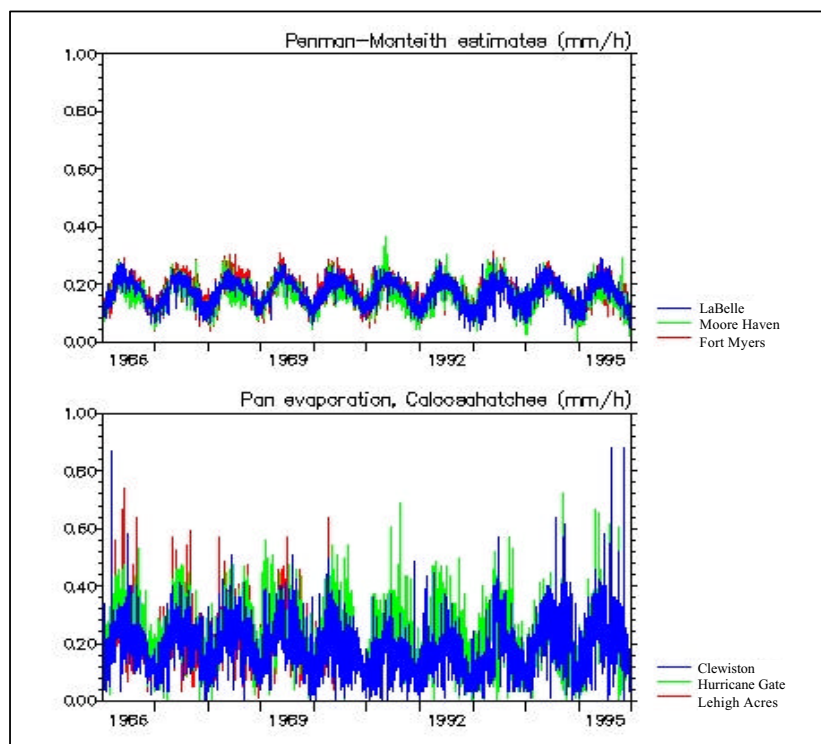
Figure G-6. Time Series of Pan ET and Penmann Estimates of Potential Evapotranspiration Rates (mm/h).

Ground Water

Geological Model

Dynamic ground water flow and potential heads are simulated by MIKE SHE. The modeling system requires a fully three-dimensional geological model describing the extent, thickness, and elevation of all major geological units including both aquifers, aquitards, and confining layers.

The Surficial Aquifer System (SAS) and the Intermediate Aquifer System (IAS) are represented in the conceptualized geological model. The aquifer system includes the following units:

- Water table aquifer

- Tamiami aquifer

- Sandstone aquifer

- Upper Hawthorn

These geological layers are assumed to account for the exchange with the river and canal network and to constitute the major source of ground water in the model area. The deeper Floridian Aquifer System (FAS) is not considered to be recharged in the model area or add to the water available in the above aquifer systems. Regional potential head maps indicate that the primary zone of recharge of the Floridian aquifer is northeast of the model area. The assumption was made in accordance with previous ground water studies in the area (Lee County Ground Water Model and Lee County Regional Water Supply Master Plan).

Borehole logs were applied to establish a geological model as part of previous ground water studies in Lee, Hendry, and Collier counties (Bower et al., 1990). The data were interpreted and processed during these studies and were made available as GIS coverages including borehole locations and corresponding elevations. Borehole data from Charlotte and Glades counties are not available and the layer thicknesses were extrapolated for Lee and Hendry counties.

Digital maps of elevation of the individual geological layers and lenses were generated from the discrete borelog information. The Tamiami and the Sandstone aquifers cover only the eastern and the weatern parts of the model area respectively. Irrigation well logs indicate that the two aquifers serve as the primary source of ground water in the basin. The extent of the two aquifers has been assessed partly from lithological information (as well logs) from irrigation wells. The water table aquifer and the upper Hawthorn layers are global found throughout the model area. Maps depicting the extent and elevation of the aquifers are displayed in **Figures G-7** through **G-10**.
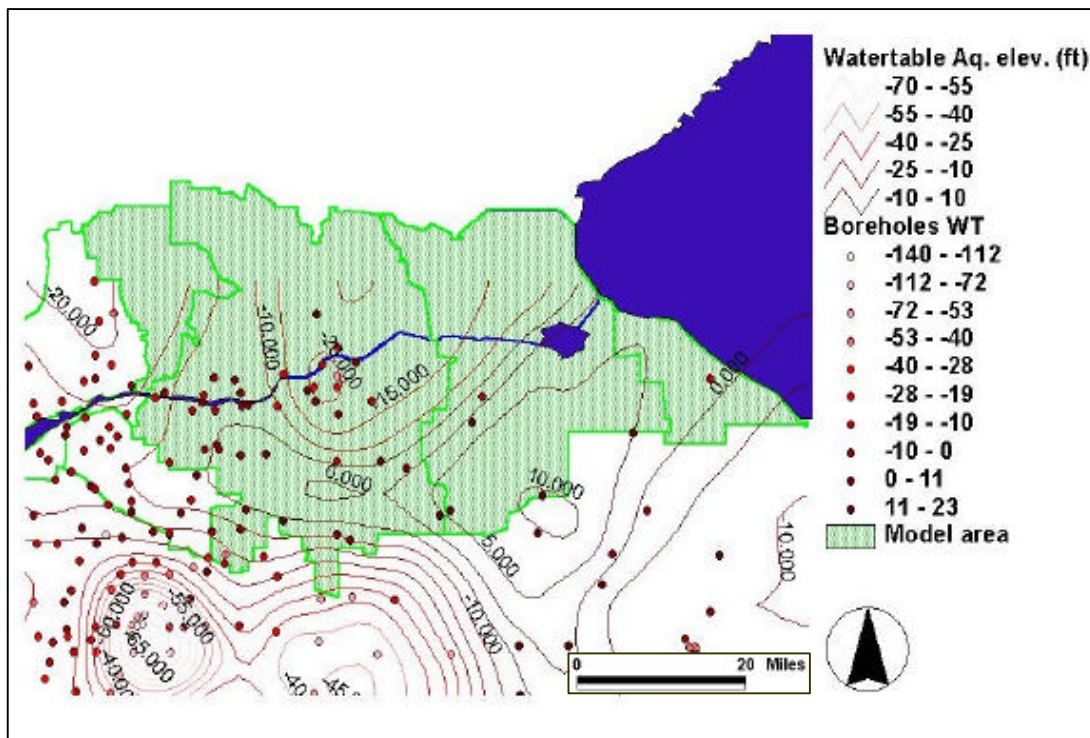
Figure G-7. Extent and Elevation Water Table Aquifer.
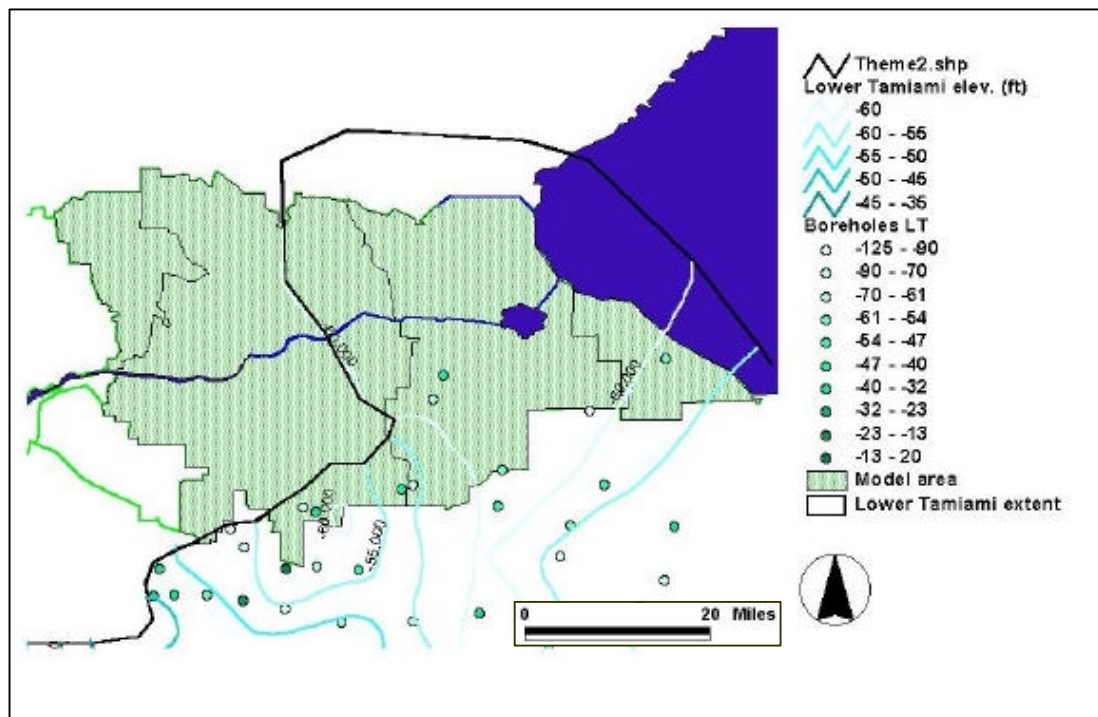
Figure G-8. Extent and Elevation of Tamiami Aquifer.
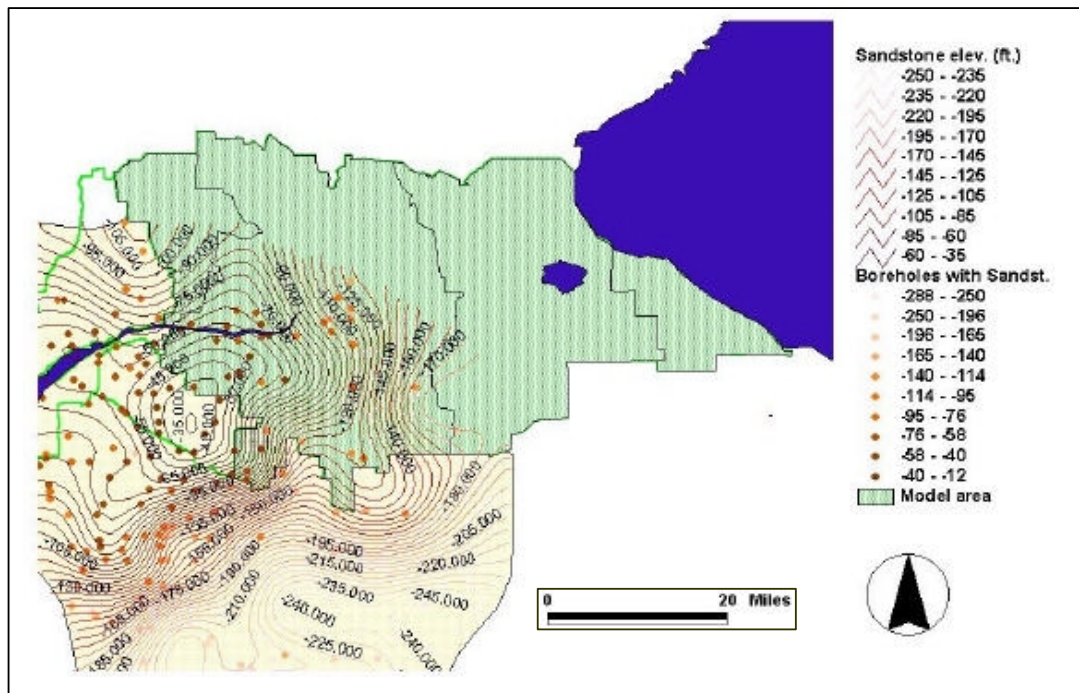
Figure G-9. Extent and Elevation of Sandstone Aquifer.
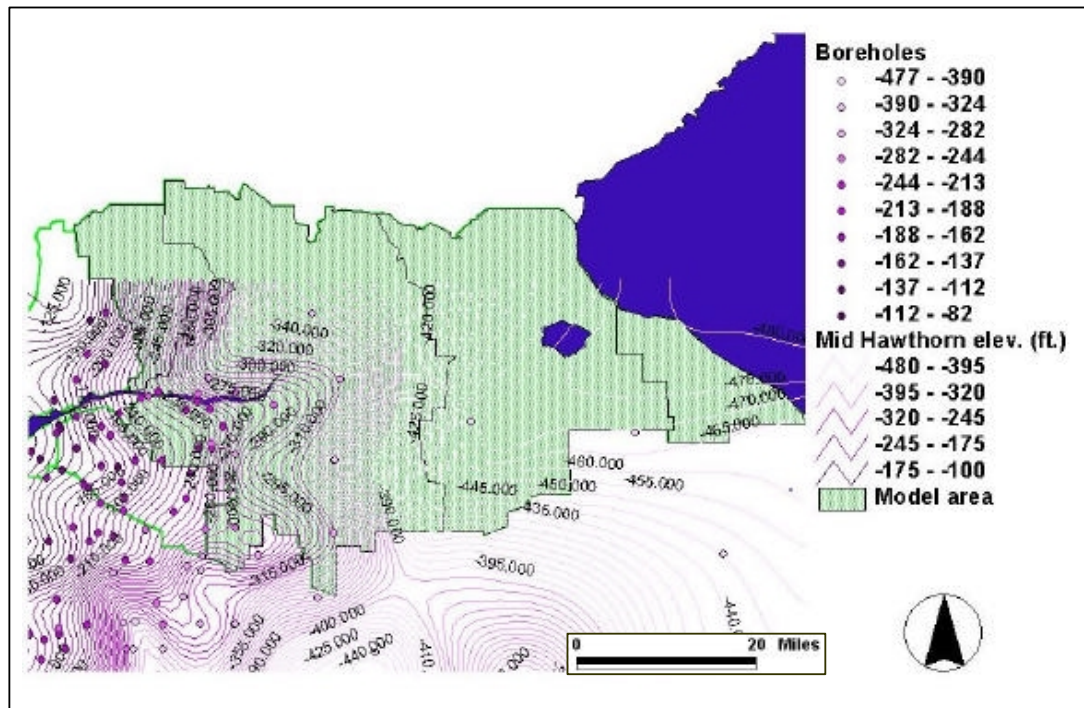
Figure G-10. Extent and Elevation of Upper Hawthorn Aquifer.

Hydrogeological Parameters

The aquifers consist mainly of marine sediments (sand, sandstone, limestone, and shells). The layers generally have high porosities and high to medium permeabilities. The Hawthorn aquifer contains finer silt and clay fraction sediments. The hydraulic properties of the layers must be specified for the ground water component. The hydrogeological parameters to be required for each layer of the model include the following:

- Horizontal and vertical conductivities
- Confined and unconfined storage coefficients

Pump test data are available at 26 locations inside the model area (**Figure G-11**). The pump test data have been associated with either the upper aquifer sequence (the water table aquifer and the Tamiami aquifer) or the intermediate aquifer sequence (mainly the Sandstone aquifer). The maximum drawdown has been observed in nearby wells pumping at a constant rate. The pump test analysis was based mainly on the Hantush-Jacob or Cooper methods. From the pump test analysis transmissivities, storage coefficients, and in some cases leakage coefficients have been derived.

The ranges of aquifer properties were determined from the pump test data within the model area and are given in **Table G-5**.

Table G-5. Hydrogeological Properties Derived from Pump Tests within the Model Area.

Surficial Aquifer	Number of Sites	Maximum	Minimum	Average
Transmissivity (ft^2/day)	7	938,368	9,500	332,849
Storage coefficient	7	1.6 e-1	4.5 e-5	2.0 e-2
Leakage	3	4.4 e-2	1.3 e-7	9.0 e-3
Intermediate Aquifer	**Number of Sites**	**Maximum**	**Minimum**	**Average**
Transmissivity (ft^2/day)	22	298,900	1,213	59,894
Storage coefficient	18	7.0 e-3	2.0 e-5	8.4 e-4
Leakage	17	2.9 e-1	2.8 e-6	1.2 e-2

The wide range of transmissivity data reflects the varying composition and properties of the geological formations. The resolution of the data is considered insufficient to produce distributed maps of the aquifer properties for each layer in the model with a 1,500-ft grid spacing. The pump test data and previous ground water studies were used to establish ranges for the model parameters. The model parameters were distributed by division into zones (i.e., subdivision of the model area into subareas with uniform parameter values).
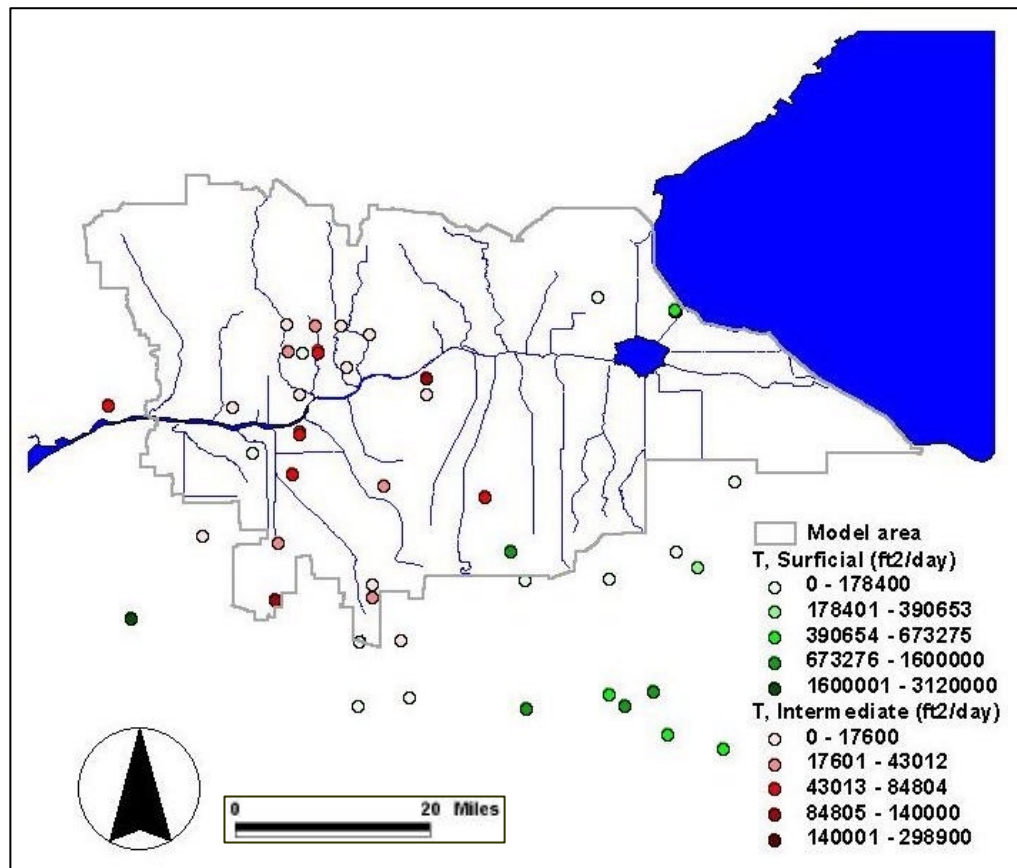
Figure G-11. Pump Test Locations and Hydraulic Parameters.

Boundary Conditions

Ground water boundary conditions are specified for all layers in the model. For the upper layer, it is assumed that surface water and ground water divides coincide and subsequently a no flow boundary was applied. The surface water divides have been subject to further analysis in order to incorporate man-made changes of drainage paths. The surface water boundary is uncertain in some parts of the basin, and flow directions may change depending on local water level changes in response to storms. Consequently, some uncertainty is associated with the ground water boundary as well. The flow, which may occur across the boundary, is insignificant with respect to the overall water balance.

A no flow boundary was also applied to the lower part of the aquifer system, with some modification to the southern boundary. Operation of irrigation ground water pumps have been reported to cause drawdowns in this area. They are believed to cause cross boundary ground water flow, which depending on the head gradient, flows in or out of the model area. Three observation wells located at the southern boundary show the water table fluctuations, including the effects of drawdowns. These time series were applied in the model to generate the dynamic head boundary used for the lower aquifer.

Ground Water Withdrawals

Well location and time series of pumping rates may be specified as part of the input for the ground water component. There is no significant industrial water use or municipal water supply in the model area.

Ground water withdraw data is not specified as part of the input for the ground water component, but is instead determined as a function of actual irrigation demand and the availability of surface water at irrigation outtake points. Surface water is generally considered to be the primary source of irrigation water. If the surface water supply is insufficient at a particular point during the simulation, ground water is then defined as second priority. The actual ground water withdrawal for a given irrigated area, at a given time is thus dependent upon the irrigation demand calculated on basis of field conditions, (e.g., soil water deficit of the root zone) and whether or not the demand can be covered solely by applying surface water.

The allocation of ground water for irrigation can be specified to take place from individual wells or it may be assumed to be uniformly distributed within the irrigation area. The storage capacity and the transmissivity of the aquifer may limit the ground water withdrawal. Demands may not be met at one time step of the simulation if the available volume of ground water is insufficient, due to a locally dewatered layer, or if the withdrawal rate exceeds the rate at which the point of withdrawal is replenished by inflow from the surrounding aquifer.

Comparing the irrigated land coverages and the location and density of permitted ground water wells indicates that no irrigation takes place in the south-central part of the

model area despite a high concentration of existing or projected wells. Further discussion on use of ground water for irrigation is given in the irrigation module description.

Ground Water Drainage

Drainage flow and interflow constitute an important contribution to the river runoff in the Caloosahatchee Basin. The observed river flow hydrograph indicates a relatively rapid response following rainfall events. Rising water tables are effectively lowered by the drainage system. Due to the dense network of ditches and tertiary canals, operation of the drainage pumps in agricultural areas, and the hydraulic structures of the drainage canals, excessive volumes of runoff and ground water are quickly routed into the primary drainage canals, thus adding to downstream peak flows in the C-43 Canal. The time lag is generally small for the Caloosahatchee Basin.

The hydrodynamic MIKE11 model is applied to simulate the flow and water level dynamics in the schematized primary canals and second order drainage/irrigation canals. Higher order canals and ditches are not represented in the river hydraulics model due to the spatial scale of the computational grid (1,500 ft) and the regional scope of the model. The higher order drainage network is dense in agricultural areas and acts effectively to reduce the water tables and prevent water logging in farmed areas. Direct hydraulic contact between aquifers and canals, and the operation of pumps both contribute to discharging large volumes of water through the drainage network.

To account for the drainage discharge in the basin, the drainage component of the MIKE SHE ground water module is included in the model. Drainage is described through the following:

- Drainage codes - areas considered to be drained

- Drainage levels - distributed maps of effective drainage levels (i.e., ground water table elevation above which drainage flow occurs)

- Drainage time constant

- Drainage options - routing of drainage water from drain levels, directly to rivers

__Drainage Codes__

The drain code map describing drained and nondrained areas was derived from GIS coverages of the entire canal network provided by SFWMD (**Figure G-12**). The density of higher order canals and the distance from each grid cell to nearby canals, determines if the area is considered drained or not. Floodplain areas that typically are inundated during parts of the simulation period have been defined as nondrained (Telegraph Swamp and Lake Hicpochee).

Drainage from each computational cell is a function of the drainage level and the time constant. The drainage outflow from the individual cells, Q_{dr}, is calculated from a
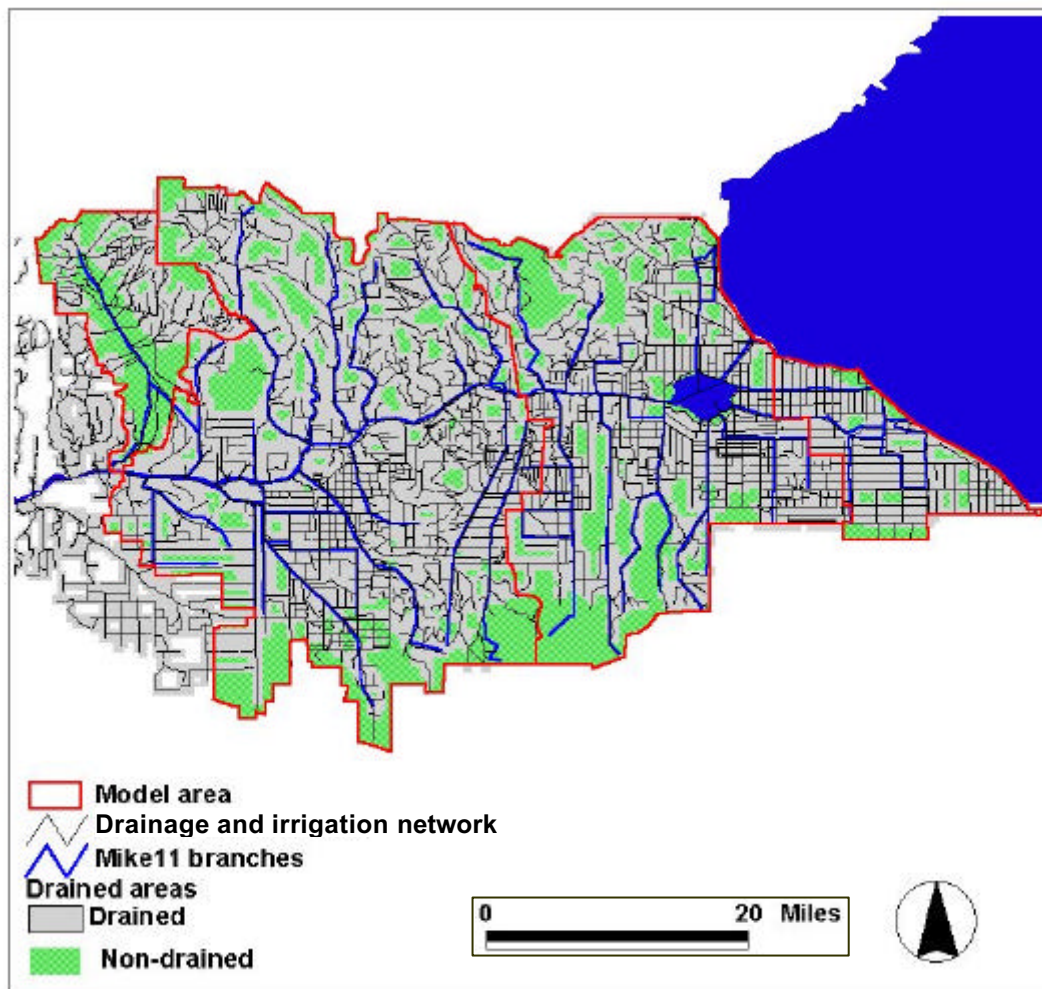
Figure G-12. Drainage Codes and River Network for the Caloosahatchee Basin Model.

linear reservoir approximation depending on the actual water table, h_{sz}, above drain level, h_{dr}, and the specified time constant, C_{dr} :

$$Q_{dr} = C_{dr} (h_{sz} - h_{dr}) A$$

where:

Q_{dr} is calculated in m^3/s, C_{dr} is specified in s^{-1}, the levels in m and the area, A, in m^2.

<u>Drainage Levels</u>

Drainage levels can not be measured directly in the field. Observed ground water head of the upper aquifer may provide information on the drainage level, but the spatial variability makes it difficult to transfer discrete information to the entire model area. Drainage levels were calculated by subtracting estimated drainage depth from the topography. The effective drainage depths were specified in the range 1.6 - 4.0 feet (ft) (0.5 - 1.2 m). This range was selected based on a number of factors including density and depth of drainage canals and land use. The drainage levels were modified during model calibration in order to simulate peak discharges and at the same time to reduce any drain flow contributions in the dry periods. The plant evaporation from the root zone may serve to reduce the ground water tables below the drainage level and thereby reduce dry period drainage outflow. In the comparison between rooting depth (specified as part of the evapotranspiration module) and the drainage level, as it has generally been assumed that drainage levels are at or above the root zone depth. The field operation of drainage pumps in citrus groves suggests that the ground water table is kept within a narrow range to avoid damage to the crop.

<u>Drainage Time Constant</u>

The drainage time constant is the reciprocal value of the mean retention time. Normally the drainage constant ranges from $1e^{-7}$ to $1e^{-3}$ s^{-1}. The delay in drain response described by the time constant affects the peak and recession of the simulated river discharge and is partially a calibration parameter. The numerous canals and the effective drainage schemes imply time constants at the high end of the interval. A uniform value of the drainage time constant, $1e^{-4}$ s^{-1}, was applied throughout the model area. The time constant is expected to vary spatially depending on whether or not the area is developed (i.e., agricultural) or undeveloped (i.e., natural areas). Surface water discharge measurements at the subbasin scale give an indication of the differences in drain response for developed and nondeveloped areas, respectively. Given the limited availability of flow data and the lumped nature of the time constant, a constant value was applied. The time constant may possibly be distributed from the land use.

Drainage Options

When the water table of the upper aquifer rises above the drain level, the excess volume is routed to a receiving point. The receiving point for drainage flow may be a depression, a specific location in the river network, or the boundary of the model area.

Routing by level implies that a receiving point for the drainage flow in a subarea of the model is determined from the slope of the drainage level. When specifying drainage depths (as a depth below the ground surface), the routing will naturally depend on the accuracy and topographical input. For the Caloosahatchee Basin, drainage patterns are determined partly by pumping and partly by gravity. In densely drained areas, the major portion of drainage flow is discharged into nearby canals. Drainage options were used to overrule the routing by levels by assuming that drainage water flows to nearby canals.

The drainage component was found to strongly affect both river discharges and ground water potential heads. The drainage model parameters were estimated from available data and general knowledge of field drainage operations.

Unsaturated Zone

The unsaturated zone extends from the ground surface to the ground water table. The depth of the unsaturated soil column is dynamic and varies throughout the simulation period. The depth of the unsaturated zone increases with decreasing ground water table and decreases when the ground water table rises. The unsaturated zone may vanish when the ground water table rises above the ground surface and saturated conditions prevail.

Due to the dynamics of the ground water table, the unsaturated zone properties must be specified from the ground surface down to the lowest ground water level during the simulation period. Hydraulic properties of the saturated zone and the unsaturated zone must be specified in an overlapping region covering the range of ground water table fluctuations.

Unsaturated zone flow is important to simulate infiltration, vertical flow through the soil column, and recharge to ground water. Simulation of the vertical soil water profile requires a detailed description of the actual soil properties. The soil water content of a profile is important with respect to calculation of evapotranspiration losses from the root zone and thus irrigation demands.

Characteristic Soils

Most of the soils of Southwest Florida are shallow and sandy with high water tables. They are characterized by high to very high permeability, high porosity, and little or no capillary rise. The texture and hydraulic properties of the soils varies on a local and a regional scale.

To provide a horizontal and vertical distribution of soil physical parameters, characteristic soil types have been identified from landscape classifications. Soils coverages from Natural Resources Conservation Service (NRCS) Soil Survey Geographical Data Base (SURRGO) were obtained from the SFWMD for all six counties (Charlotte, Collier, Glades, Hendry, Lee, and Palm Beach), which are part of the Caloosahatchee Basin. There are approximately 70 different soil-mapping units in the basin. Many of these mapping units have similar physical characteristics and are assumed to behave in a similar hydrologic manner. For simulation purposes, the soils can be classified in different hydrologic response groups. These hydrologic response groups are flatwoods, marshes and ponds, sloughs, depressions, rock (shallow soils on limestone), and unsuitable. The hydrologic response groups are based on the range productivity landscape classes. Six different landscape types have been identified and five of those have been related to characteristic soil types (**Table G-6**). These soils were selected to represent each landscape class. These soils provide a range in soil physical characteristics typical of the corresponding landscape type.

Table G-6. Landscape Type and Associated Soil Type.

Landscape Type	Soil Type
Flatwoods	Immokalee
Depressions	Winder
Marsh and Ponds	Sanibel
Rock	Boca
Sloughs	Pineda

Each landscape type is distributed and associated with a standard soil profile including the soil horizons found from field surveys. Each soil type in the profile is represented by its thickness and soil physical parameters (**Figure G-13**).

Soil Physical Parameters

The soils were evaluated by comparison of the physical characteristics of the soil profile and the hydrologic behavior of the soils. The soil profiles were reviewed for differences in soil texture, hydraulic conductivity, depth to a horizon that would impede percolation, and variability of the soil properties (**Table G-7**). It was determined that all soils were sandy with some fine sands and loam. A MIKE SHE soil database was prepared for 55 soils by Southwest Florida Research and Education Center. Each soil sample represents a specific soil sample taken at a specific depth. The database includes retention curves and hydraulic conductivity curves. Soils with a large areal extent in the basin were selected for hydraulic simulation using FHANTM2. The data for the simulations were obtained from the DRAINMOD model and data from the county soil surveys. The results indicated that most of the soils behaved in a similar manner, except deeper soils, which produced less runoff.
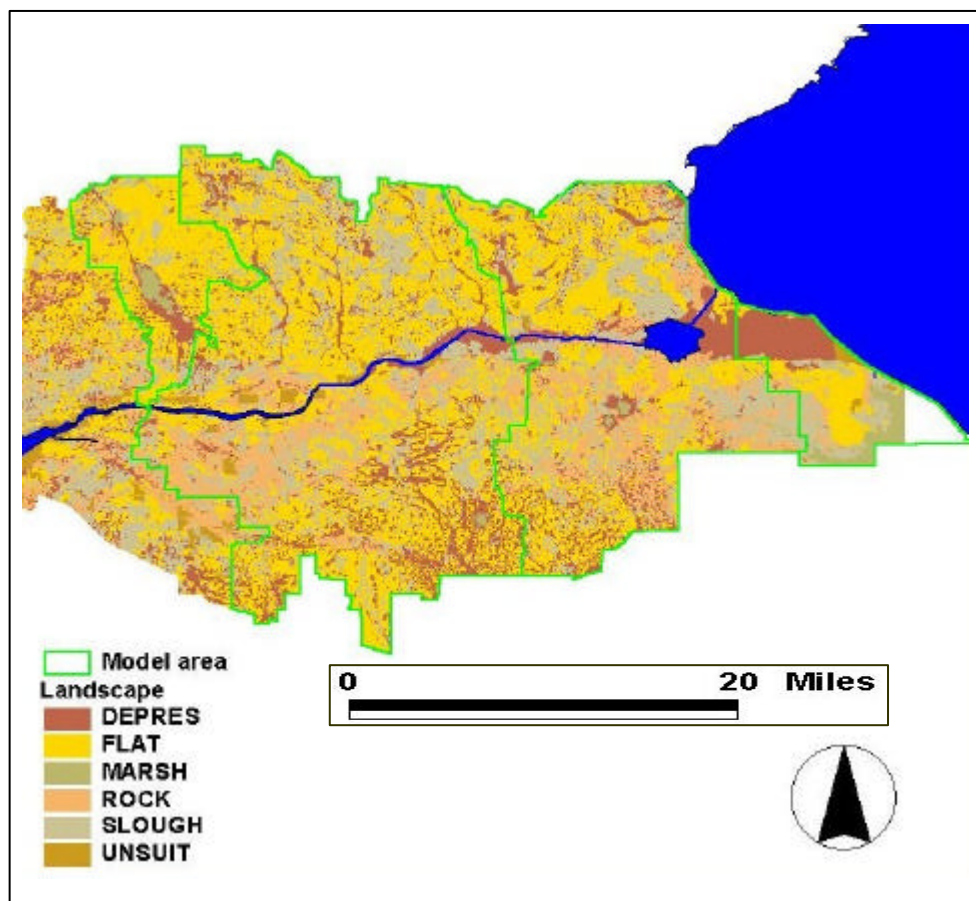
Figure G-13. Distribution of Soil Columns in Caloosahatchee Basin from Landscape Types.

Table G-7. Soil Physical Parameters Entered into the Unsaturated Zone Database.

Profile Number and Landscape Type	Soil Type and Depth	Saturated Hydraulic Conductivity K_s [m/s]	Saturated Water Content Q_s [percent]	Water Content at Field Capacity Q_{fc} [percent]	Water Content at Wilting Point Q_w [percent]	Residual Water Content Q_r [percent]
(1) Flatwoods	Immokalee A1 (0.0-0.1 m)	2.0e-4	0.42	0.079	0.03	0.01
	Immokalee AE (0.1-0.23 m)	1.1e-4	0.42	0.095	0.057	0.031
	Immokalee E1 (0.23-0.41 m)	8.6e-5	0.39	0.084	0.025	0.015
	Immokalee E2 (0.41-0.91 m)	1.0e-4	0.38	0.074	0.017	0.01
	Immokalee Bh2 (0.91-1.4 m)	6.1e-6	0.38	0.225	0.07	0.043
	Immokalee Bw/Bh (1.4-23 m)	7.5e-5	0.38	0.112	0.033	0.02
(2) Slough	Pineda E (0.0-0.13 m)	8.0e-5	0.464	0.085	0.033	0.02
	Pineda Bw1 (0.13-0.33 m)	8.0e-5	0.449	0.085	0.023	0.02
	Pineda Bw2 (0.33-0.58 m)	6.4e-5	0.422	0.095	0.009	0.01
	Pineda E1 (0.58-0.91 m)	5.3e-5	0.408	0.076	0.012	0.02
	Pineda Btg/E (0.91-1.37 m)	3.1e-7	0.351	0.31	0.11	0.1
	Pineda Cg (1.37-22 m)	1.1e-6	0.380	0.347	0.162	0.1
(3) Depression	Winder A1 (0.0-0.08 m)	3.6e-5	0.374	0.175	0.024	0.014
	Winder E (0.08-0.33 m)	5.7e-5	0.37	0.092	0.008	0.004
	Winder Btg (0.33-0.58 m)	7.4e-6	0.43	0.395	0.153	0.101
	Winder C1 (0.58-0.89 m)	4.1e-6	0.332	0.225	0.038	0.021
	Winder C3 (0.89-21.7 m)	1.9e-6	0.355	0.303	0.107	0.062
(5) Rock	Boca A (0.0-0.08 m)	1.1e-4	0.487	0.088	0.04	0.029
	Boca E1 (0.08-0.23 m)	9.7e-5	0.46	0.080	0.034	0.023
	Boca E2 (0.23-0.36 m)	8.0e-5	0.408	0.064	0.024	0.015
	Boca Bw (0.36-0.64 m)	5.4e-5	0.396	0.071	0.009	0.006
	Boca Btg (0.64-22.64 m)	8.3e-7	0.347	0.0311	0.122	0.071
(6) Marsh	Sanibel Oa1 (0.0-0.12 m)	2.0e.5	0.55	0.715 (?)	0.197	0.2
	Sanibel A1 (0.12-0.23 m)	9.4e-5	0.51	0.370	0.025	0.01
	Sanibel C1 (0.23-0.66 m)	1.4e-4	0.37	0.069	0.013	0.01
	Sanibel C2 (0.66-21.7 m)	1.1e-4	0.38	0.062	0.011	0.01

Model Set-up

Vertical flow and water content of the unsaturated soil was calculated using a maximum time step of 6 hours. The computational time steps were automatically updated during the simulation to avoid numerical instability following the input of significant rainfall volumes.

The vertical flow in the unsaturated soil column and the water content profile was calculated solving the equation for gravity flow disregarding capillary effects.

The unsaturated zone does not require specification of boundary conditions. The ground water table of the upper aquifer constitutes the lower boundary for the unsaturated zone within each of the soil columns. The upper boundary may act as a flux boundary when the soil has sufficient infiltration capacity. When the infiltration capacity is exceeded, a head boundary is applied depending on overland water depth. When ground water tables rise above the ground surface, the unsaturated zone flow calculations are replaced by the ground water component.

The vertical flow in the unsaturated zone is calculated in each time step for all of the 12,997 computational columns.

The unsaturated zone classification option of MIKE SHE is used to reduce the total computational time required to solve the unsaturated zone flow in each time step. This option allows the user to transfer simulated flow between soil columns of similar characteristics (i.e., rainfall, potential evapotranspiration, soil type, land use type, and depth to the ground water table). Because this classification option does not distinguish between flooded/nonflooded areas, or irrigated/nonirrigated areas, it was not used for Caloosahatchee Basin ISGM.

Land Use and Evapotranspiration

Land use data are primarily used for determining vegetation characteristics applied for simulation of actual evapotranspiration in MIKE SHE.

Evapotranspiration accounts for the bulk of water losses from the Caloosahatchee Basin. The water is lost to the atmosphere reducing the water available for surface and subsurface runoff. The ET module of MIKE SHE simulates the following:

- Interception and evaporation from vegetation cover
- Soil and free water surface evaporation
- Plant transpiration from the root zone

The actual rate of evapotranspiration is calculated from (Kristensen and Jensen, 1975):

$$E_{at} = f_1(LAI) \cdot f_2(\Theta) \cdot RDF \cdot E_{pot}$$

where:

E_{at} is the actual rate of evapotranspiration, f_1 is a damping function ($0 < f_1 < 1.0$) describing effects of vegetation density (leaf area index, LAI), f_2 a damping function ($0 < f_2 < 1.0$) describing the dependency on soil water content, Θ, and RDF is the root distribution function (vertical distribution of root mass).

The leaf area index (LAI) is calculated as the total leaf area of the vegetation per unit ground surface area, and is a measure of the vegetation surface area available for transpiration. The index may be time varying for seasonal vegetation while perennial vegetation may be considered constant. Harvested crops such as sugarcane and truck crops are described by vegetative stages covering the growth period.

RDF is the percentage of active root mass in a specific depth of the root zone. A rooting depth is specified (extinction depth) and the root mass is distributed vertically by an exponential function. The root mass distribution and the vertical soil moisture profile of the root zone affects the actual evapotranspiration rate in each depth interval of the root zone and as a total, integrated for the entire root zone. The rooting depth may be highly variable depending a number of factors including climate, soil properties, ground water table, and unsaturated zone/soil moisture profile. In MIKE SHE, RDF is specified for each vegetation type (vegetation database).

Land Use and Vegetation Specific Data

The LAI and RDF parameters are vegetation specific. The distribution of vegetation parameters is based on the identification of the dominant characteristic vegetation/land use types in the basin.

Land use maps are applied to distribute vegetation specific parameters. Land use maps based on aerial photos and field inventories exist for 1988 and 1995 as GIS polygon coverages and were utilized to determine vegetation specific parameters. The land use in the basin has been classified from SFWMD land use and land cover classification codes (**Tables G-8** and **G-9**). Coverages exist at different level of detail. The highest level (level I) includes agriculture, barren, forest, water bodies, rangeland, urban, and wetlands.

Table G-8. SFWMD Land Use and Land Cover Classification Codes.

Level I	Level II
(A) Agriculture	(AC) Sugarcane (AP) Pasture (AM) Groves, fruit (AF) Animal production
(B) Barren	(BB) Beaches (BP) Mines, pits (BS) Spoil areas (BL) Levees
(F) Forest uplands	(FE) Coniferous (FO) Nonconiferous (FM) Mixed
(H) Water	
(R) Rangeland	(RG) Grassland (RS) Scrub and bushland
(U) Urban	(UR) Residential (UC) Commercial (UI) Industrial (US) Institutional
(W) Wetlands	(WF) Forested fresh (WN) Nonforested fresh (WS) Forested salt (WM) Nonforested salt (WX) Mixed forested and nonforested fresh

Table G-9. Land Cover Types Represented in the Model and Corresponding SFWMD Codes.

Model Land Cover Types	MIKE SHE Code	SFWMD Land Cover Classification
Urban	5	U
Citrus	1	AM
Pasture	2	AP
Sugarcane	3	AC
Truck crops	10	---
Grass	4	UR
Dense upland forest	6	F
Sparse upland forest	7	F
Grassland, shrub	8	R
Wetlands, marsh	9	W, H

The MIKE SHE GIS module was applied to export land use maps from ArcView into MIKE SHE grid format and used as input for the evapotranspiration module (**Figure G-14**).

For each vegetation/land cover type, a set of parameters were entered in to the MIKE SHE vegetation database. The parameters include empirical constants used in the equations describing actual evapotranspiration (C_1, C_2, C_3, C_{int}, and A_{root}) and time series for RDF, LAI, Kc (crop coefficient), and irrigation requirements. The parameters are given at each growth stage of the crop or vegetation.

Table G-10. Land Use and Irrigation.

Land Use	Irrigation Method	Irrigation Source
Urban	None	None
Citrus	Micro Spray	Canals/Ground Water Wells
Sugarcane	Subsurface	Canals/Ground Water Wells
Truck crops	Micro Spray	Canals/Ground Water Wells
Pasture	None	None
Grass	None	None
Dense forest	None	None
Sparse forest	None	None
Grass, shrub	None	None
Wetlands, marsh	None	None

RDF and LAI were estimated for each type of vegetation. LAI values vary within each land use/cover classification. The range is due to the wide variability of the land cover included in each class. However, there was insufficient information to split these classes into more specific vegetation classes and no field data were available. The LAI values applied ranges from 1.0 to 6.0.

Similar to LAI, the rooting depth varies with vegetation type, soil type, local water tables, and drainage. The RDF varies in depth for different vegetation types and within each vegetation class. Maximum rooting depth and effective rooting depth may differ significantly and the active root mass may vary with varying field conditions (sufficient irrigation or drought). The regional modeling scale and the complexity of root mass distribution does not allow description of local variation. The RDF is therefore a partly physically based representing actual rooting depth and a partly lumped parameter representing overall vegetation characteristics in each 1,500-ft grid cell. Estimated values in the range of 1.6 - 4.9 ft (0.5 -1.5 m) were applied.

For more details on the irrigation component of MIKE SHE see the Irrigation section in this Appendix.
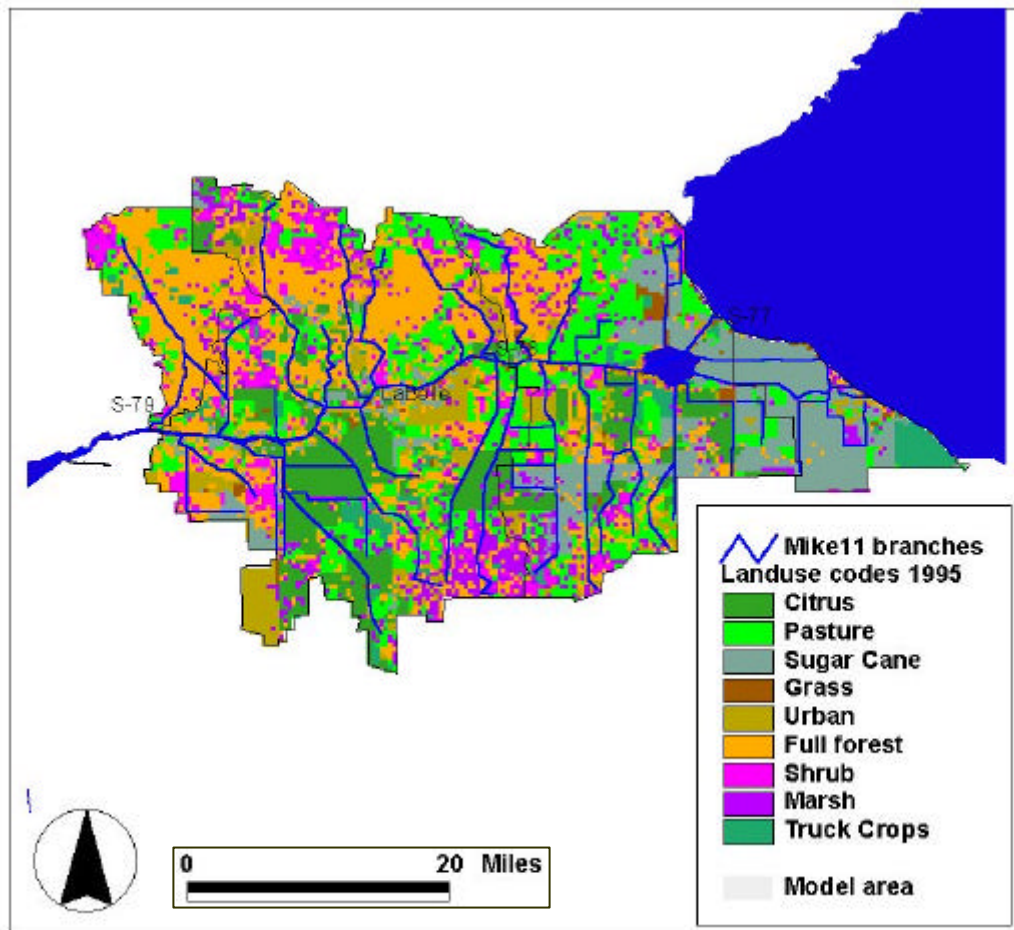
Figure G-14. MIKE SHE Land Cover Codes 1995.

Overland Flow

Overland sheetflow occurs when the water depth on the ground surface is larger than zero. Ponding of water at a specific location is a result of the following:

- Insufficient infiltration capacity of the unsaturated soil column

- Ground water tables rising above ground

- Overland flow from neighboring areas

- Drainage flow to low-lying areas

Due to high infiltration rates and moderate to high horizontal conductivities of the upper aquifer, significant overland flow generally occurs only in the basin during storms. The duration of inundation is longer at wetlands covering smaller parts of the basin, but the topography of such areas does not promote overland flow.

Surface Slope

The overland flow direction and velocity is determined by the ground surface slope. The input surface topography map was based on five-foot contour maps supplemented by discrete spot elevations. The data were collected and processed by SFWMD. The basic data and the derived topographical model are available as GIS coverages. A 500-ft map was created as input for the model by interpolation of the data.

The model area is relatively flat with little topographical relief. Consequently, a topographical model based on five-foot contours would not be fully represent the depression storage and flow direction in the relatively flat central parts of the basin. Isolated wetlands and ponds may not be described by a five-foot contour resolution and the 1,500-ft computational grid resolution. To investigate the overland flow and storage in more detail, a finer computational grid was required.

More important is the depression storage (i.e., low lying areas receiving overland flow or drainage flow). The surface detention volume is described by the topography (**Figure G-15**). Ponding water accumulates as depression storage until the water level exceeds topographical thresholds separating the depression from surrounding areas. Ponded water may also infiltrate, limited either by the infiltration capacity of the underlying unsaturated zone, or when the soil is entirely saturated, the leakage coefficient between the overland component and the saturated zone component.

Model Parameters

The governing equation for overland flow (2-D Saint-Venant) requires specification of a Manning number, and a detention storage and leakage coefficient. The Manning number describes the ground surface resistance flow within each computational cell and depends mainly on land use. A uniform value of 10 $m^{1/3}$/s was applied. Detention storage is a threshold value that describes the level where overland water depth flow is
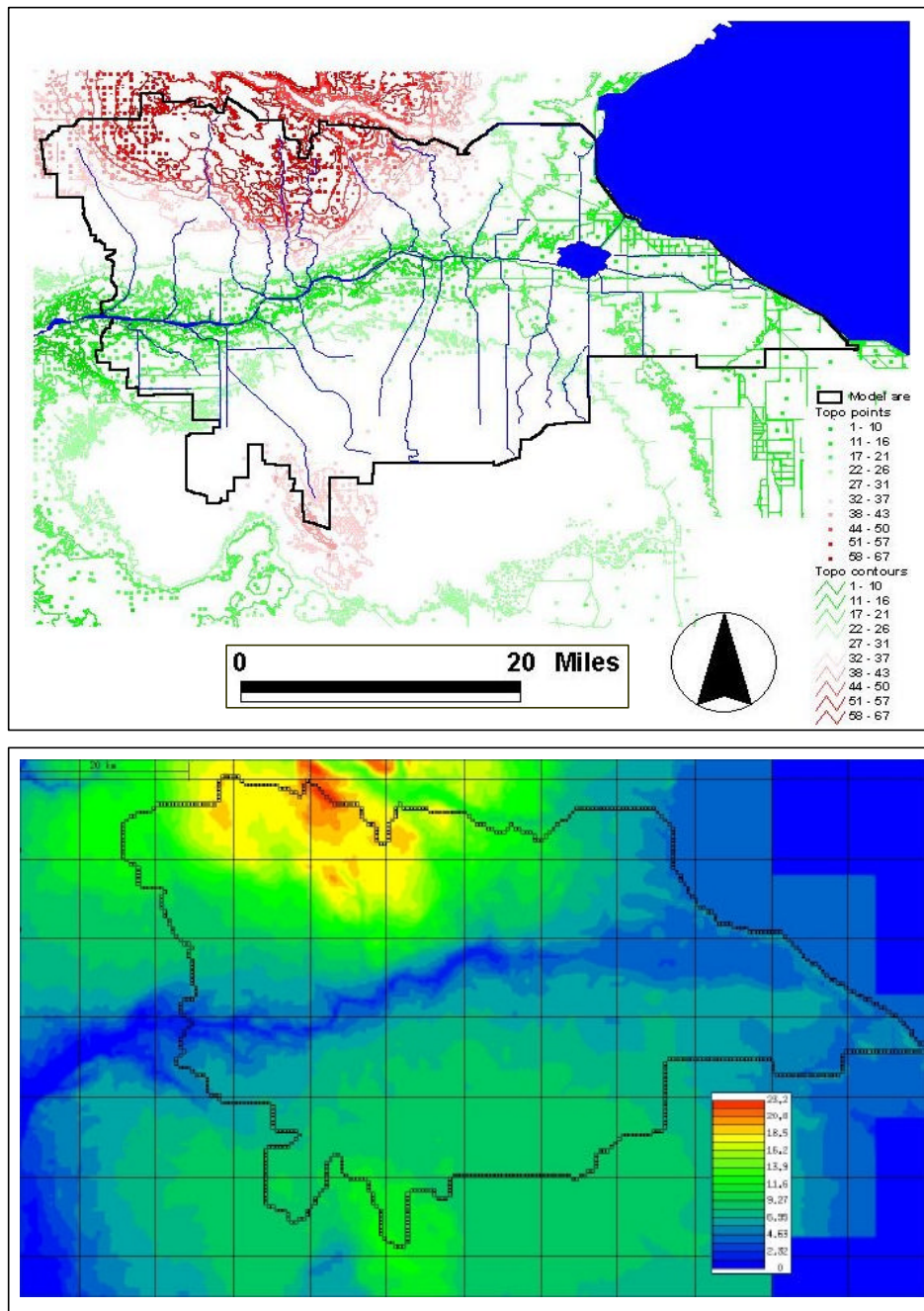
Figure G-15. MIKE SHE Digitized Data and Interpolated Topographical Model (elevations in meters).

initiated. The detention storage value depends on surface properties, which may vary within a short distance. Distributed average values for each computational cell may be given. Here, a uniform value of 0.4 inches (10 millimeter [mm]) was applied. Exchange of flow between overland flow and ground water may take place when the soil is completely saturated. The leakage coefficient is used to describe the hydraulic contact between ground water and overland flow. A uniform value of $1 \cdot 10^{-6}$ s^{-1} was applied.

Simulation

Overland water depth and flow velocities are calculated in maximum time steps of 6 hours. The time step is reduced during periods of high rainfall intensity.

Rivers and Canals

Flows and water levels are simulated within all major drainage and irrigation canals in the basin. MIKE11 is a fully unsteady river hydraulics model, dynamically coupled to MIKE SHE. This implies that the integrated modeling system fully accounts for the dynamic exchange of water between the river and other model components. In each time step, the exchanged volumes are updated in all computational points of the model. Inflow and outflow from the river may take place as ground water seepage (calculated from simulated water level differences between the aquifers and the river reaches), overland flow (surface runoff driven by actual overland water depths and surface slope) and drainage flow (ground water drainage flow routed to rivers/canal network).

River Network

The Caloosahatchee River (C-43 Canal) and its major tributaries were included in the river hydraulics model (MIKE11). Due to the lack of cross-sectional data and the limitations on the number of computational nodes, the canals represented directly in the MIKE11 model were chosen based on the following criteria:

- All major irrigation canals in order to describe the allocation of irrigation water

- All major drainage canals and natural streams contributing to C-43 Canal discharge

- Rivers/canals draining major swamps or wetlands

A total of 47 branches are included as part of the river hydraulics model **Figure G-16**. In the western part of the basin, drainage is gravity driven, while drainage flow in the eastern part and pumps control irrigation supply in secondary canals. The irrigation network represented in the Caloosahatchee Basin ISGM is depicted in **Figure G-17**.
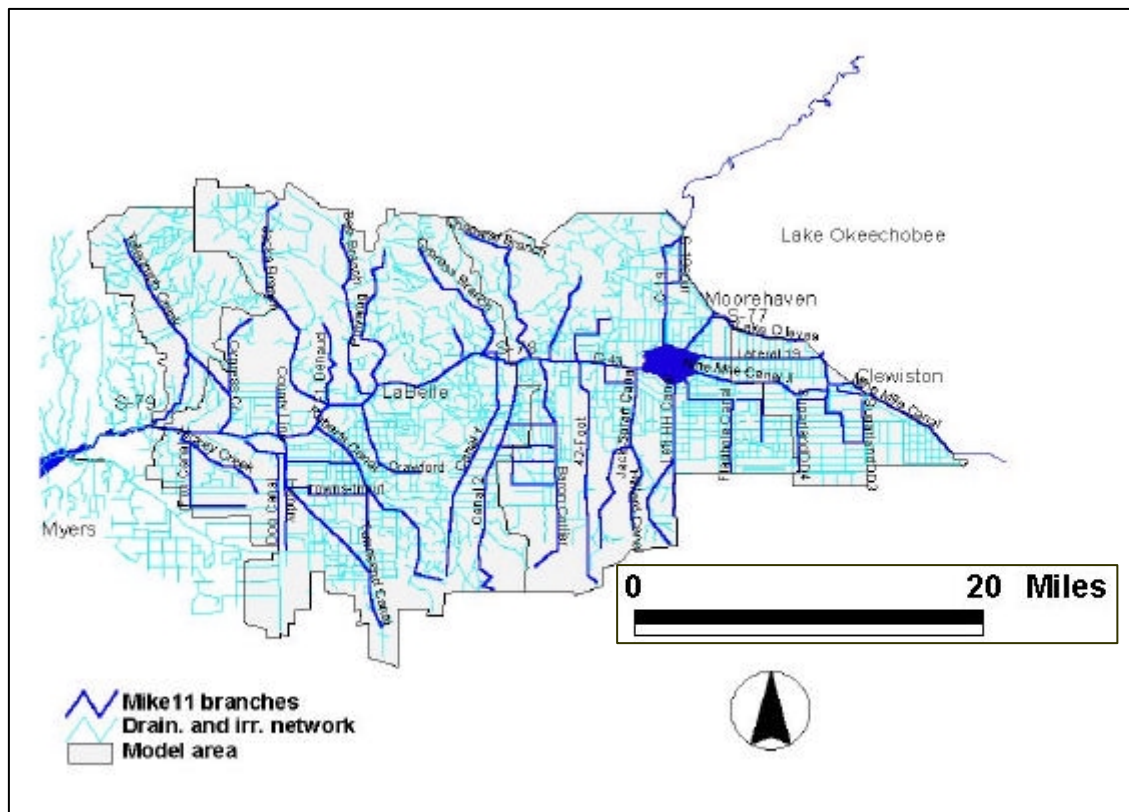
Figure G-16. The River and Canal Network Represented in the Caloosahatchee ISGM.
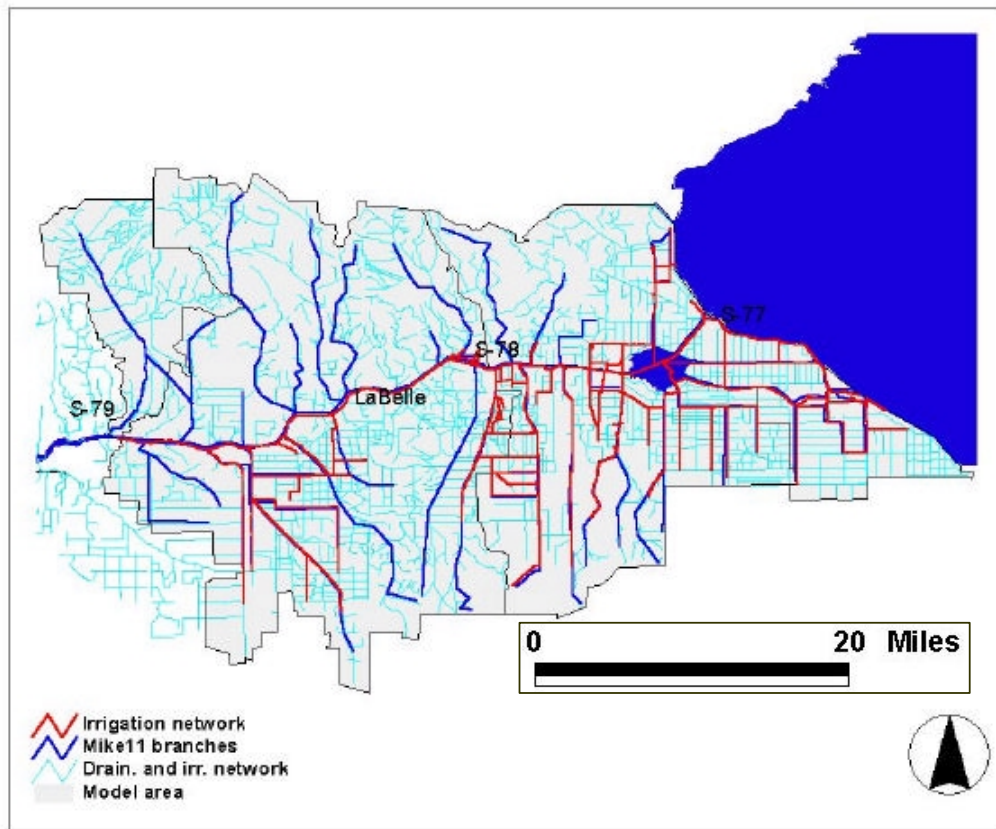
Figure G-17. The Irrigation Network Represented in the Caloosahatchee ISGM.

Cross-Section Data

The geometry of each river branch is described in terms of cross-sections (**Table G-11**). Cross-sections and datum are important in the determination of both conveyance capacity and storage capacity at different reaches of the river system.

Cross-section data is generally scarce for most of the river network included in the model. Design data from construction of the C-43 Canal and a few major branches major canals exist at SFWMD. The available data cover the period from 1962-1992. Cross-sections from parts of the C-43 Canal, Jack's Branch, County Line Ditch, Canal 1, Canal 2, C-19, the 42-Foot Canal, and Hilliard Canal were provided by SFWMD from a number of reports. No surveyed cross-sections exist.

Due to the limited amount of measured cross-section data, estimated trapezoidal cross-sections were estimated from topographical data. Where cross-section data were available, dimensions were specified in accordance with design data (e.g., the C-43 Canal).

Boundary Conditions

Boundary conditions were specified at upstream and downstream ends of the river network. A constant flow boundary condition of 0.88 ft^3/s (0.025 m^3/s) was applied to avoid numerical instability. The flow is not significant with respect to the water balance of the basin. The total flow introduced through the boundary conditions is less than 35 ft^3/s (1.0 m^3/s) or 0.47 inches/year (12 mm/year), which is negligible in terms of the total water balance.

Time series of observed discharge from Lake Okeechobee (S-77) were used as an upstream discharge boundary condition for the C-43 Canal.

Time series of observed water levels downstream of Franklin Lock were used as a downstream boundary condition for the C-43 Canal.

Hydraulic Structures

The drainage and irrigation network is controlled by a large number of hydraulic structures (**Figure G-18**). In the C-43 Canal, the combined weir/lock structures are operated for navigational purposes and to maintain acceptable water levels for irrigation purposes. Many of the secondary branches are dug canals, which were constructed to provide sufficient conveyance capacity for drainage, sufficient storage capacity for irrigation, or for both. To supply surface water to the upstream parts of the basin during dry periods, water is pumped upstream from the C-43 Canal in stages separated by weirs or gates. Weirs are typically built in connection with pump stations. The pumps are activated when the water level upstream of the weir drops below the minimum acceptable level for irrigation. Water is diverted from the main secondary irrigation canals by pumps or by tertiary ditches and canals. During dry periods, the pumps on the primary canals may

Table G-11. Cross-Section Dimensions for Canals Represented in the River Hydraulics Model[a].

Branch name	Width feet (meters)	Depth feet (meters)
C-43 Canal	164-367 (50-112)	16-26 (5-8)
Hickey Creek	33-66 (10-20)	7-10 (2-3)
Fox Canal	56-66 (17-20)	10-13 (3-4)
Dog Canal	56 (17)	10 (3)
Roberts Canal	16-108 (5-33)	3-10 (1-3)
26-00082-W	43 (13)	10 (3)
Crawford	43-52 (13-16)	10 (3)
Canal 1	66 (20)	7-13 (2-4)
Canal 2	79 (24)	7-13 (2-4)
Baron Collier	180 (55)	16 (5)
42-Foot	79 (24)	10-13 (3-4)
Jack Spratt	66 (20)	7-10 (2-3)
Hilliard Canal	66 (20)	7-10 (2-3)
Left HH Canal	49-118 (15-36)	7-10 (2-3)
Right HH Canal	49 (15)	7 (2)
Flaghole Canal	118 (36)	10 (3)
Nine Mile Canal	66 (20)	7 (2)
Lateral 19	66 (20)	7-13 (2-4)
Lake Okee.levee	66 (20)	7-13 (2-4)
Cypress Creek	23 (7)	10 (3)
County Line	33 (10)	10-13 (3-4)
Jacks Branch	33 (10)	13 (4)
Bee Branch	23 (7)	10 (3)
Polywog	33 (10)	13 (4)
Dead Man's Branch	33 (10)	7 (2)
Cypress Branch	39-46 (12-14)	1-13 (3-4)
Chaparal Branch	39 (12)	10-13 (3-4)
22-00243-W1	23 (7)	10 (3)
C-19	66 (20)	7-10 (2-3)
C-19 Spur	46 (14)	10 (3)
Townsend Canal	79 (24)	13 (4)
Hendry	89-108 (27-33)	13 (4)
Telegraph Creek	33-66 (10-20)	7 (2)
Townsend Tributary	20 (6)	10 (3)
Branch38	98 (30)	10 (3)
Branch39	98 (30)	10 (3)
Branch40	98 (30)	10 (3)
Branch41	98 (30)	10 (3)
Jack Spratt X	26 (8)	10 (3)
Flag Hole X	118 (36)	7 (2)
SugarlandDD4	118 (36)	7 (2)
S-310	66 (20)	7 (2)
Nine Mile Canal II	66 (20)	7 (2)
SugarlandDD3	118 (36)	7 (2)
Fort Denaud	23 (7)	10-13 (3-4)

a. The cross-section widths refer to the main canal; floodplains are not included.

run continuously to supply water to the upper reaches. The pumping rates are determined by irrigation demands and the availability of water in the C-43 Canal.

All major hydraulic structures were included as part of the MIKE11 model. Data for 28 weirs and 15 pumps were incorporated in the river set-up. The majority of control structures are located in the southern part of the basin. Data for the hydraulic structures were provided by SFWMD. In addition to the location of each hydraulic structure and the water permits they supply, required data include weir height, weir width, levels for pump operation, pump capacity, and culvert dimensions.

Floodplains and Inundated Areas

The Caloosahatchee Basin is generally flat with a number of floodplains or depressions (sloughs and swamps) adjacent to the river branches. At high water levels following rainfall events, the river inundates the floodplain. When the river water levels recede, water stored on the floodplain drains back to the river. Dynamic floodplain simulation of the river/floodplain interaction is important in order to describe flow attenuation and surface water storage.

Lake Hicpochee and Telegraph Swamp are two major floodplain areas connected to the C-43 Canal and Telegraph Creek respectively. Their storage and conveyance capacity is represented by wide cross-sections incorporating both main canal and floodplain features. The cross-sectional width increases with increasing water levels and flooding occurs as the water table rises above the bank level.

Floodplain data were derived from the topographical model by comparing river bank elevations to the surrounding surface elevations. The five-foot contour map may not represent the areas potentially flooded by riverbank overtopping in accurately. The approximate retention volume of the low lying areas along the river branches assumed to be flooded is, however, sufficient to obtain flow attenuation and interaction between inundated areas and the subsurface domain.

With emphasis on basin water balance simulations rather than detailed hydraulics and flooding, the river model is sufficiently detailed at the coarser, regional scale.

Key calibration parameters for the MIKE11 simulation are Manning bed resistance numbers and leakage coefficients for the exchange of water with the aquifer.

The Manning numbers applied in the MIKE11 model range from 20 to 50 $m^{1/3}$/s. From comparison of discharge time series at S-77, S-78, and S-79, it was observed that the delay in time and the reduction in peak flows in the C-43 Canal is very limited. Consequently, high Manning numbers were applied in this part of the system. Both primary and secondary canals are generally kept free of vegetation.

The bed leakage coefficients were specified for each branch of the river system and describe the hydraulic contact between the river and the aquifer. The exchange of flow
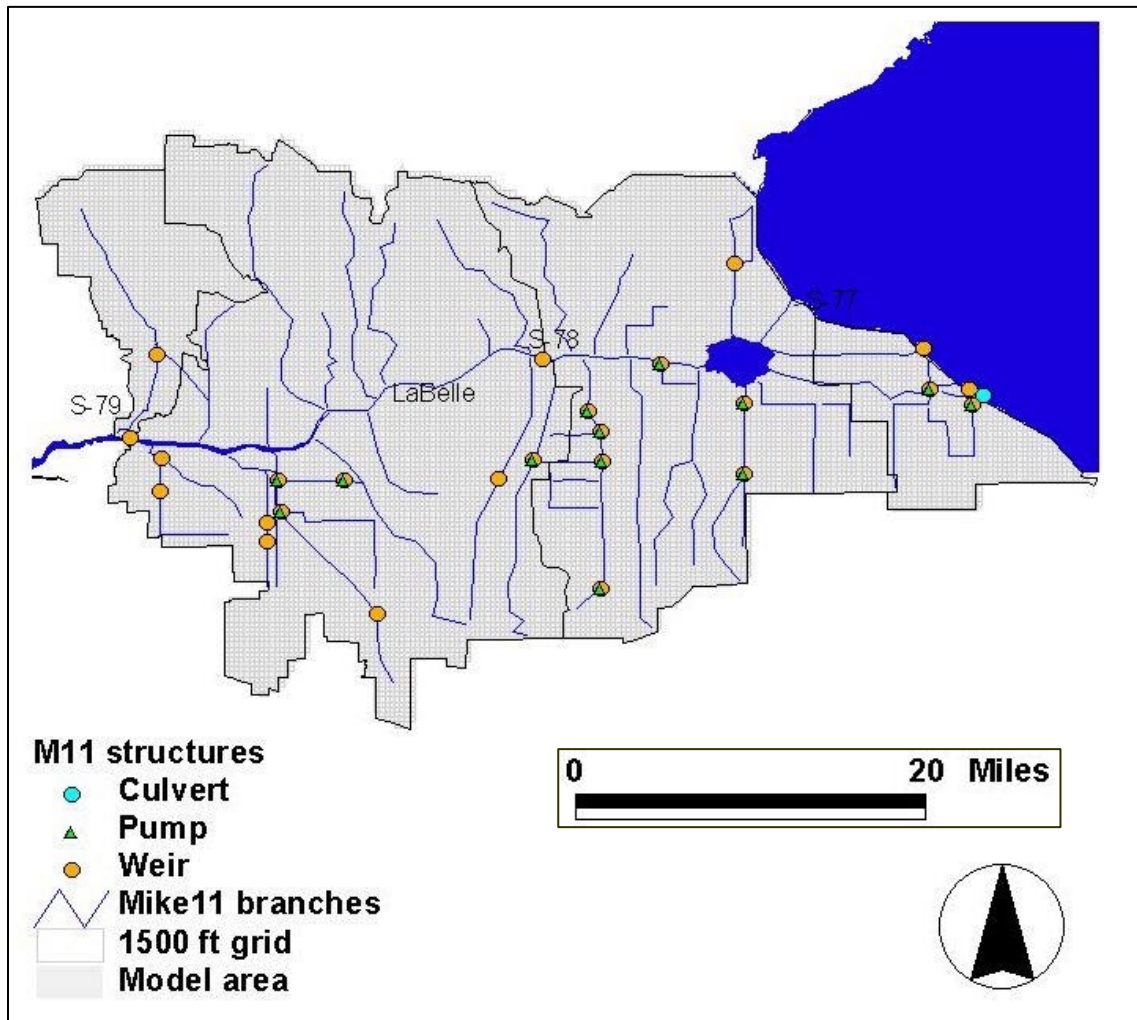
Figure G-18. Surface Water Hydraulic Structures in the Caloosahatchee ISGM.
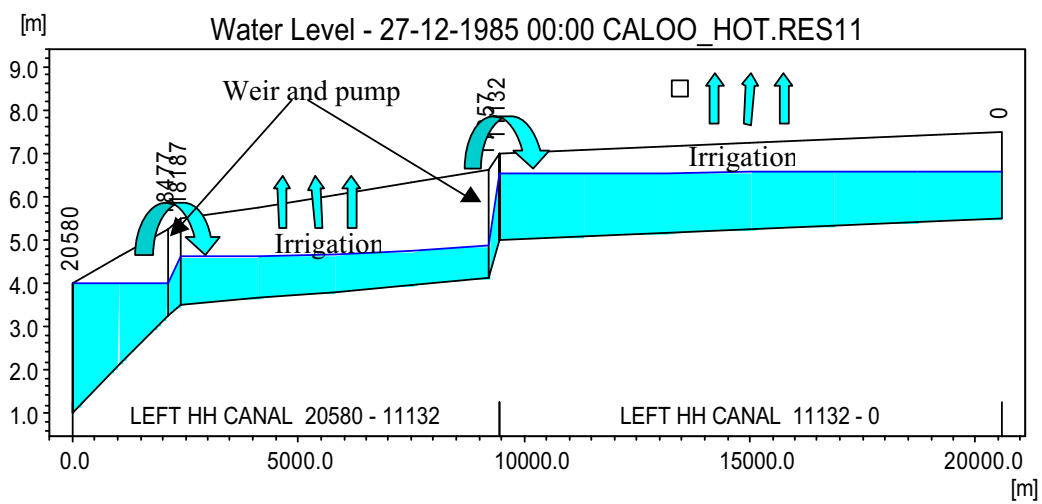
Figure G-19. Example of Combined Weir and Pump Structure in MIKE11.

is described by a Darcy approximation as a function of the head gradient and the leakage coefficient. The hydraulic contact is relatively high except for parts of the system where organic matter and sedimentation (e.g., clays/silts) reduce the conductivity along the canal bed lining. A uniform value of $1e^{-6}s^{-1}$ was applied for the entire river network. The leakage coefficient is likely to vary, but the available data has not support a physical description.

Simulation

The computational time step applied in MIKE11 is 10 minutes. The time step has been chosen from the time scales and numerical constraints.

Irrigation

The volume of water used for irrigation is important in determining the water budget of the Caloosahatchee Basin. Agricultural development in the basin has lead to increasing irrigation water demands. During dry periods, water is diverted from Lake Okeechobee to meet this demand. In order to assess the effects of possible future imposed restrictions on Lake Okeechobee water (Everglades restoration), in combination with further agricultural development in the basin, a closer analysis of actual irrigation demands is required.

The purpose of simulating irrigation is to quantify demands and describe the effects of irrigation water allocation. The irrigation module (MIKE SHE IR) is applied in order to accomplish the following:

- Generate spatially and temporally varying irrigation demands depending on the simulated field conditions

- Simulate allocation of water from ground water wells, irrigation canals or from sources outside the model area to meet the irrigation demand

- Simulate the effects on the basin water balance

Farmers irrigate to eliminate crop water stress and thereby avoid reductions in yield related to insufficient water supply. The feasibility of irrigating is, however, closely linked to costs for providing water and the plant response to water stress. Optimization of irrigation water supply in the field is often not possible due to lack of information on actual evapotranspiration rates. Soil water content could be used as an indicator but generally no unique criteria exist on irrigation practices with respect to timing of irrigation and the volumes applied. The management element of the irrigation depends on the operation of pumps and hydraulic structures at the field level. On the larger scale, little is known on the operation of structures at each field station. Instead the irrigation module is applied focusing on the objectives of the irrigation (i.e., to provide sufficient water for crop transpiration). The water resources in the basin are to a large extent controlled to achieve optimal conditions for the crop.

Irrigated Crops

A number of different crops in the basin are irrigated. Four major crops represented in the vegetation classification depend partially or entirely on irrigation. Sugarcane, citrus, and truck crops (vegetables) must be irrigated to ensure profitable agricultural production. Improved pasture areas may also be irrigated in parts of the basin, but in general it is assumed that pasture areas are not irrigated.

Irrigated Areas

Two sources of information exist for describing which areas are considered to be irrigated. Land use maps and SFWMD water permit coverages were applied to produce a map of irrigated areas. Comparison reveals some discrepancies which introduces uncertainty on the total irrigated area. The bulk of irrigated land (approximately 90 percent), however, was identified in both sets of data. The individual polygons of the derived GIS coverage was applied to determine the extent of irrigated command areas (i.e., areas being supplied from the same irrigation sources).

Irrigation Demand

Little data exist that document irrigation practices (i.e., when farmers start irrigating and the actual supply rates and volumes). Field surveys conducted in the Caloosahatchee Basin do not provide any operational rules, which may be assumed valid for the basin in general. Irrigation demand depends on many factors and is highly variable in time.

Calculation of irrigation demand relies on estimates of actual evapotranspiration. This approach is based on available meteorological data and aims at calculating the supplemental water required to maintain potential rates of evapotranspiration for the respective crops.

The use of an integrated hydrological model, that simulates the water content in the root zone and the actual evapotranspiration rates, offers the opportunity of an alternative approach. By focusing on the purpose of irrigation rather than either describing fixed rates of supply or attempting to describe the actual operation of structures at field level, it is possible to formulate irrigation targets and determine the actual irrigation requirement to meet those targets.

In the MIKE SHE irrigation module, the irrigation demand may either be given for each agricultural area prior to the simulation or it may be regulated from a set of management criteria. Some of the criteria include the following:

- Maximum allowable soil water deficit in the root zone
- Maximum allowable crop water stress (E_{act}/E_{pot})
- Prescribed time series of crop water requirements

The first option was used for the Caloosahatchee Basin model. In the vegetation database, the targeted upper and lower limits of the average root zone soil water content is specified as:

$$\Theta_{fc} - 0.1(\Theta_{fc} - \Theta_w) < \Theta < \Theta_{fc}$$

where:

Θ is the actual mean soil water content of the root zone, Θ_{fc} and Θ_w are the soil water content at field capacity and wilting point respectively. The total soil water volume available for transpiration through plant uptake is $(\Theta_{fc} - \Theta_w)$. Whenever the actual soil water content reduces below 90 percent of this volume during the simulation, the maximum allowable water deficit of the root zone is exceeded and irrigation water is supplied. The demand is calculated as $(\Theta_{fc} - \Theta)$. If available the water is allocated at associated irrigation sources and supplied at the rate, $(\Theta_{fc} - \Theta)/dtuz$, in the following time step of the simulation. The allowable deficit is given relative to soil properties to account for the differences in soil properties in the model area.

The soil water content is kept close to field capacity to prevent any reduction in actual rates of evapotranspiration due to soil water availability. To keep the soil water content within this narrow range, irrigation water is supplied at a high frequency corresponding to an optimized operational schedule.

Using field capacity as the soil water reference level for irrigation is considered an appropriate approximation for citrus and truck crops, while the water table control used for irrigation in sugarcane fields may not fully be represented. Data on the actual water table management in the sugarcane fields were not available to support a different approach.

Irrigation Water Allocation

The water is supplied by conjunctive use of surface water and ground water. The availability of surface water and ground water varies in the basin. As a general rule, the use of surface water is less costly than withdrawal of ground water. Ground water is mainly used in areas without an irrigation canal network or when the surface water resource is scarce.

A link between irrigation command areas (fields) and specific locations for allocation of water was established by GIS preprocessing. Each irrigated area was associated with a prioritized list of river locations (defined by branch name and chainage) and/or ground water wells from where the required irrigation water volume is allocated (if available). Limits were specified for each source in terms of a minimum river flow or ground water potential head. At a given time, the generated demand is met by, in order of priority, exhausting the available resource at the specified locations until sufficient water has been provided. If the total volume of available water does not cover the demand shortage occurs.

A general assumption was adopted for the water allocation. First and second priority was given to nearby irrigation canals, while third priority is given to shallow ground water wells. Exceptions were made in areas with no irrigation canals and a large density of irrigation ground water wells and in the eastern part of the basin where water is pumped directly from Lake Okeechobee. The irrigation set-up was modified by SFWMD based on water permit data. In a number of the irrigated areas, individual wells were specified as the primary source of water.

The canal flow and storage may not be sufficient to meet irrigation demand, in which case, it for most areas would allocate water from the aquifer. Almost all canal cross-sections and canal bed levels were based on general assumptions relating to the canal dimensions due to lack of surveyed data and some uncertainty with respect to which irrigated areas are supplied from which points in the canals. Consequently, the ground water allocation may locally be overestimated if the available water in the canals is underestimated. As ground water tables are reduced in response to irrigation withdrawals, the head gradients and exchange between aquifer and canals is affected.

Irrigation set-ups were developed for both 1988 and 1995 conditions (**Figures G-20** and **G-21**). **Figure G-22** displays a screen capture of the user interface for linking irrigated areas and irrigation sources.

Irrigation Water Distribution Method

Irrigation water may be distributed in the fields by means of the following methods:

- Sheetflow - irrigation supplied at one location and distributed by local overland gradient (flooding)

- Sprinkler - irrigation added to rainfall

- Drip irrigation - irrigation supplied below the canopy avoiding interception losses

It must be stressed that the model terms used for distribution methods should be seen in relation to the grid scale applied in the model. For MIKE SHE and any other grid-based model, the irrigation water is uniformly distributed to represent the average conditions of the area. Subscale variations are not represented and can only be dealt with by adopting a finer grid resolution.

In the Caloosahatchee Basin, micro irrigation is a widespread irrigation technique, especially in citrus groves. Micro jets are placed at the base of each tree, wetting only the immediate surrounding area. Consequently, soil evaporation between rows is minimized. Sugarcane areas are typically irrigated by flooding or through water table control (i.e., maintaining high water tables by increasing canal water levels). When water is pumped into the field it is distributed based on the local surface slope. At the spatial scale applied in the model, such local variation can not be described, but must be described as the
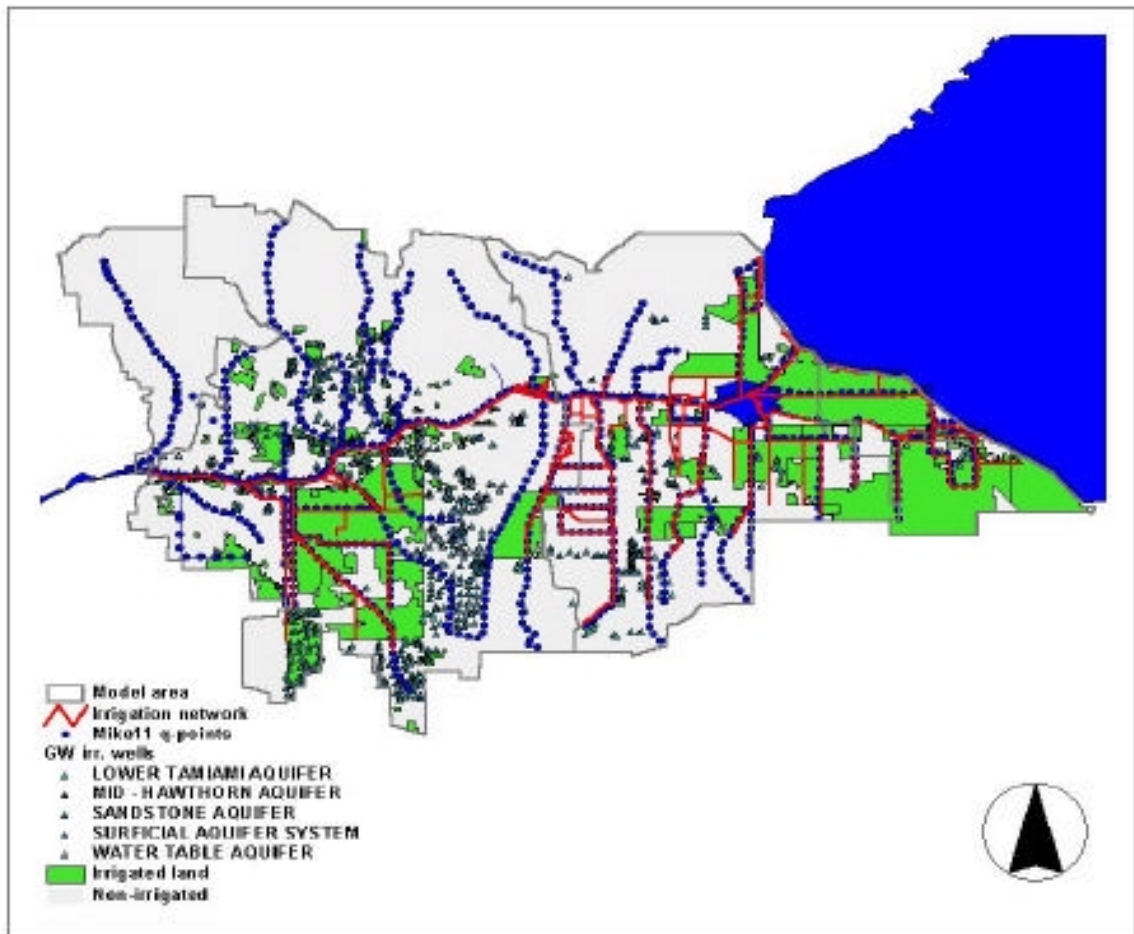
Figure G-20. Irrigated Areas and Sources, 1988.
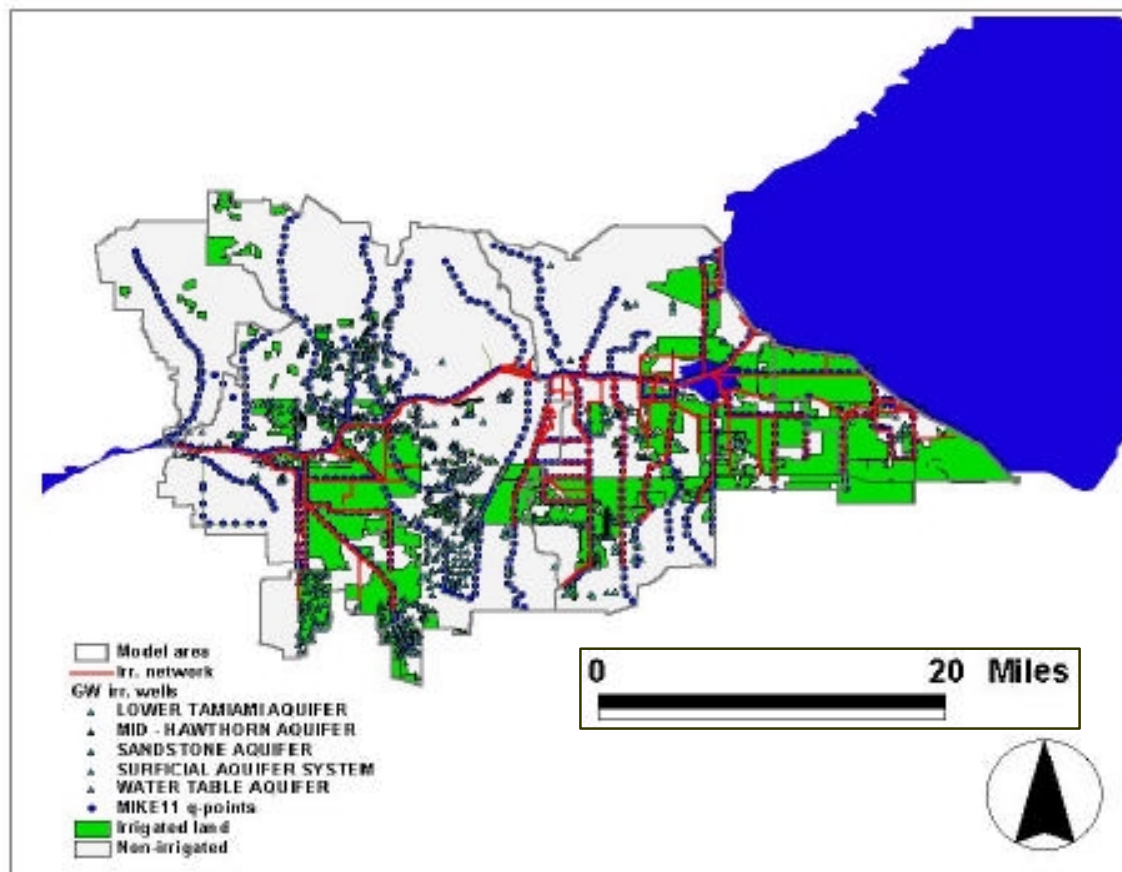
Figure G-21. Irrigation Areas and Sources, 1995.
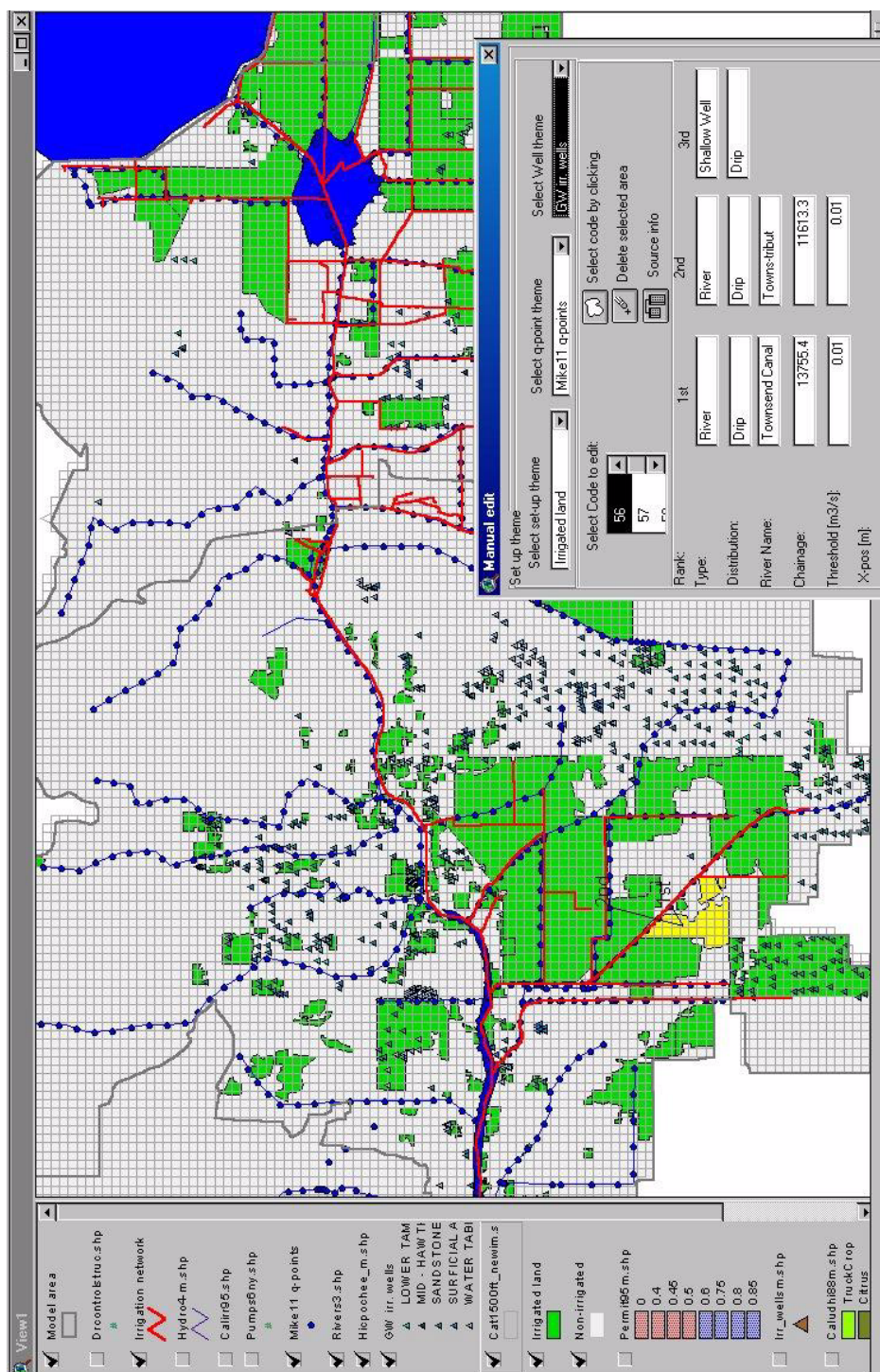
Figure G-22. Screen Capture of the User Interface for Linking Irrigated Areas and Irrigation Sources.

average of the area. The drip irrigation option was used for the entire basin. An alternative method may be considered to describe sugarcane areas in greater detail.

Irrigation Efficiency and Conveyance Losses

To meet actual field demands water, is allocated from irrigation canals or ground water wells.

The efficiency of the irrigation scheme is always less than 1.0, implying that water is lost from the source to the point of application. In addition, the water distributed in the field may not be available for crop transpiration due to a number of factors:

- the supply rate exceeds the infiltration capacity of the soil water is lost due to overland flow or free surface evaporation
- the soil is already saturated
- water percolates below the root zone

If the soil becomes saturated when the ground water tables rise, there is no soil water deficit in the root zone and subsequently demand and supply equals zero. Due to the relatively high conductivities of the soils in the Caloosahatchee Basin and the frequent supply of irrigation water, the infiltration capacity is rarely exceeded.

In each time step, the irrigation water demand is approximately equal to the water lost from the root zone from evapotranspiration. The demand is calculated as the water deficit below field capacity (i.e., the point where free drainage of the soil and infiltration to the ground water occurs). On irrigated areas, the percolation to the surficial aquifer is thus limited.

Canal conveyance losses are accounted for as canal-aquifer exchange along the river branches included in the MIKE 11 model (all primary canals) until the irrigation outtake points. Seepage from the canal system may occur if the head gradient is positive from the canal towards the aquifer. This does not change the demand, but in response to significant conveyance losses, a higher pumping rate from the C-43 Canal is required to maintain water levels in the irrigation canal. The water seeping into the aquifers will eventually reappear as a baseflow contribution in the downstream part of the canal system.

MODEL CALIBRATION AND VALIDATION

The Caloosahatchee Basin Integrated Surface–Ground Water model (ISGM) covers the freshwater portion of the Caloosahatchee Basin. It is an integrated model that includes a suite of model components that simulate overland flow, flow in rivers and canals, flow in the unsaturated and saturated zones, evapotranspiration losses to the atmosphere, and an extension that describes irrigation water use and its distribution.

MIKE SHE is based on a fully-dynamic coupling between the different parts of the hydrological cycle. It is distributed, implying that spatial and temporal variation within the model area is accounted for. MIKE SHE is characterized as distributed and physically based (i.e., measured field data may be entered into the model and the model parameters have a clear physical interpretation).

The objective of the model development is to provide a modeling tool capable of assessing the impact of the extensive conjunctive use of ground water and surface water on the total water balance. For the model to be used for predicting effects of future management initiatives, it must be able to simulate historical records in the basin.

The performance of the model depends on the following:

- Model conceptualization - the extent to which simplifications, assumptions, and generalizations correspond to actual conditions
- Quantity and quality of basic input data - uncertainties associated with measured data
- Model parameters applied - the extent to which they apply for the model area and if they are supported by field data
- Accuracy, availability, and distribution of field calibration references
- The numerical models ability to represent the flow processes

The calibration process is primarily aiming at obtaining a set of model parameters, which provide a satisfactory agreement between model results and field observations. The definition of 'satisfactory' is not clear, hence more objective criteria should be introduced bearing in mind the purpose of the model. Choosing objective criteria which ensures an accurate calibration is, however not trivial. Emphasis must be put on variables with pronounced effect on the water balance. The Caloosahatchee Basin model was calibrated for the period 1986-1990, a period chosen in order to represent both dry and wet conditions.

The model validation serves to verify that the deviation between observed and simulated values within the calibration period also applies to an independent time period. The period 1994-1998 was selected for model validation.

The model was calibrated against available time series of observed canal discharges and ground water heads. A wide range of outputs can be derived from the model and apart from objective statistical based criteria the model must be evaluated through the overall capability of representing common hydrological and physical features of the basin (i.e. flood duration, flood extent, and irrigation water demand etc.).

It is important to stress the nonuniqueness of the final set of parameters obtained from the calibration process. The number of parameters and their possible combinations is high. Field data are used to limit the range of model parameters and thereby reduce the

number of possible outcomes. Even by imposing restrictions supported by field data, several sets of parameters may yield an acceptable calibration. Consequently, the parameter combination used should be seen as one likely alternative.

Input Data and Model Parameters

The input data requirements and model parameters for the fully integrated MIKE SHE model are comprehensive (**Table G-12**). Each component of the model applies a range of input data types and parameters. The parameters may be physically measurable or empirical specific to the equations solved in the model.

Table G-12. List of Model Input and Parameters for MIKE SHE.

Model Component	Model Input	Model Parameters
MIKE SHE SZ Saturated zone flow	Geological model (lithological information) Boundary conditions Drainage depth (drain maps) Wells and withdrawal rate	K_h, Horizontal hydraulic conductivity K_v, Vertical hydraulic conductivity S, confined storage coefficient S, unconfined storage coefficient Drainage time constant
MIKE SHE UZ Unsaturated zone flow	Map of characteristic soil types Hydraulic conductivity curves Retention curves	Ks, Saturated hydraulic conductivity Qs Saturated water content Q_{res} Residual water content Q_{eff} Effective saturation water content pFc, Capillary pressure at field capacity pFw, Capillary pressure at wilting point n, Exponent of hydraulic conductivity curve
MIKE SHE ET Evapotranspiration	Time series of vegetation Leaf Area Index Time series of vegetation root depth	C_1, C_2, C_3 : Empirical parameters C_{int} : Interception parameter A_{root} :Root mass parameter Kc : Crop coefficient
MIKE SHE OC Overland and river/canal flow (MIKE11)	Topographical map Boundary conditions Digitized river/canal network River/canal cross-sections	M, Overland Manning number D, Detention storage L, Leakage coefficient M, River/canal Manning number
MIKE SHE IRR Irrigation module	Irrigated areas Irrigation sources (pumps/canals/reservoirs) Distribution method (sheet, sprinkler, drip) Source capacity	Eact/Epot, crop water stress factor (target ratio between actual and potential evapotranspiration rates)

The conjunctive use of surface water and ground water requires a resource assessment including both surface and subsurface domains. The calibration was

consequently aimed at obtaining a satisfactory agreement for both the C-43 Canal discharge and observed ground water heads in the shallow and deep aquifers.

The canals are the primary source of irrigation water and in the calibration process highest priority was given to simulating the dry period canal flow; a second priority to obtain the approximate storm peak discharges and total accumulated runoff. The lateral contributions to river flow are overland flow, seepage between aquifer-canals, and drainage flow. The storm discharge is dominated by overland and drainage flow contributions. Given the limited surface slope and the relatively high infiltration capacity of the soil, overland sheetflow only adds to the canal flow during high intensity storms. The ground water drainage and interflow is thus important to the rising leg and recession of the simulated hydrograph. Consequently, the calibration of surface water was focused on the drainage response. The drainage depth and drainage time constant of areas considered drained has been subject to changes. The drainage depth was varied between 1.6 - 4.1 ft (0.5-1.25 m). Increasing the drainage depth effectively increases the volume of ground water discharged into the canals and thus increases the downstream peak flows.

The drainage water level was compared to root depths of the vegetation. In cropped areas the drainage level is controlled to avoid long-term water logging that potentially could cause damages to the crop. Conversely, the root mass distribution may reflect the actual depth to the ground water table (i.e., development of deeper roots secures the water uptake during droughts). In general, the drainage level should effectively drain the ground water when the root zone is completely or partly saturated. Conversely, the plant water uptake of water during dry periods may reduce the water tables significantly below the drainage level. If significant drainage flow persists during dry periods, it may be seen as an indication of too low drainage levels. As only scarce information exists for describing the distributed drainage levels, it has been treated as a calibration parameter.

Other calibration parameters include conductivities and storage of the aquifers, saturated hydraulic conductivity of the unsaturated soils, aquifer-canal leakage coefficients, and Manning numbers of the river/canal. The effect of changing root depth and LAI was also investigated.

The simulated low flow was a function of surface water diversion at S-77, storage in the canals, the aquifer baseflow and the irrigation water outtake from the canals. Applying small leakage coefficients reduced the aquifer baseflow and adjusting drainage levels to minimize dry period drainage flow. The crop parameters affecting actual evapotranspiration and corresponding irrigation demand were tested by changing the root depth 1.6 - 4.9 ft (0.5-1.5 m). The rooting depth was not found to change the total demand significantly in irrigated areas. The LAI (1.0-6.0) was generally not limiting the actual evapotranspiration.

Calibration

To test whether the selected set of model parameters applied to both dry and wet conditions, the model was calibrated for a period including both dry and wet years (1986-1990).

Field measurements constituted the primary calibration references. In the Caloosahatchee Basin model river/canal discharges and ground water levels were used to calibrate the model (**Figures G-23**, **G-24**, and **G-25**). The time series of observed potential heads were collected as part of previous ground water flow studies for Lee, Hendry and Glades counties. They were assigned to the deep and shallow aquifers respectively (water table aquifer and Sandstone aquifer) from well screen information. All of the available observation wells are located in the southern part of the model area. A total of 12 shallow wells and 12 deep wells are found inside the model area south of Caloosahatchee River (C-43 Canal). Calibration of ground water heads was not possible in the remaining part of the model area due to lack of data.

Discharges were recorded at the C-43 Canal at Moore Haven, Ortona and Franklin Lock (S-77, S-78, and S-79). Moreover discharges were measured at Canal 19 at S-342, S-47b, and S-47d for a shorter period. The flow data at S-78 includes the total runoff from the eastern part of the basin.

Apart from field measurements, the model may be evaluated from a more general view using "soft calibration references". These could include the following:

- Aerial photos of flooding

- Irrigation water demand

- Water balance

- Flow dynamics and general physical characterstics

The model results were evaluated from the general knowledge and understanding of the model area. As no 'hard' data in terms of measurements were available, the comparison between simulations and the field conditions was qualitative, implying the overall pattern and performance of the hydrological system was verified against the common conception of the basin hydrology.

The first phase of the Caloosahatchee Basin Integrated Surface/Ground Water model established a regional model for the freshwater part of the basin in a 1,500-ft computational grid. It was thus only possible to compare model results with field conditions on the coarser scale. Hence, the lumped nature of model input and parameters on to a 1,500-ft grid does not support interpretation on a detailed subscale level. By decreasing the grid scale in a local model it is, however, possible to analyze the model results in further detail. Development of detailed models was not within the scope of this study.
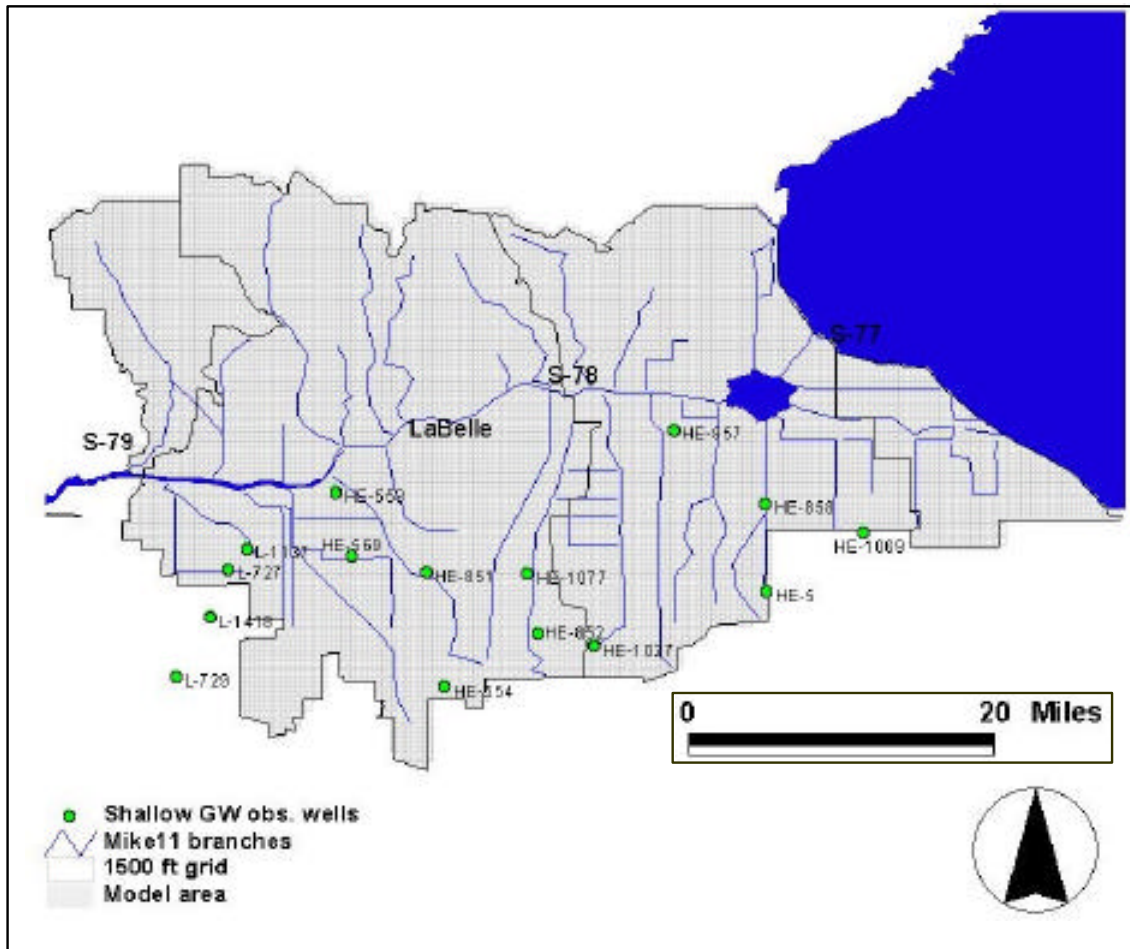
Figure G-23. Observation Wells, Shallow Aquifer.
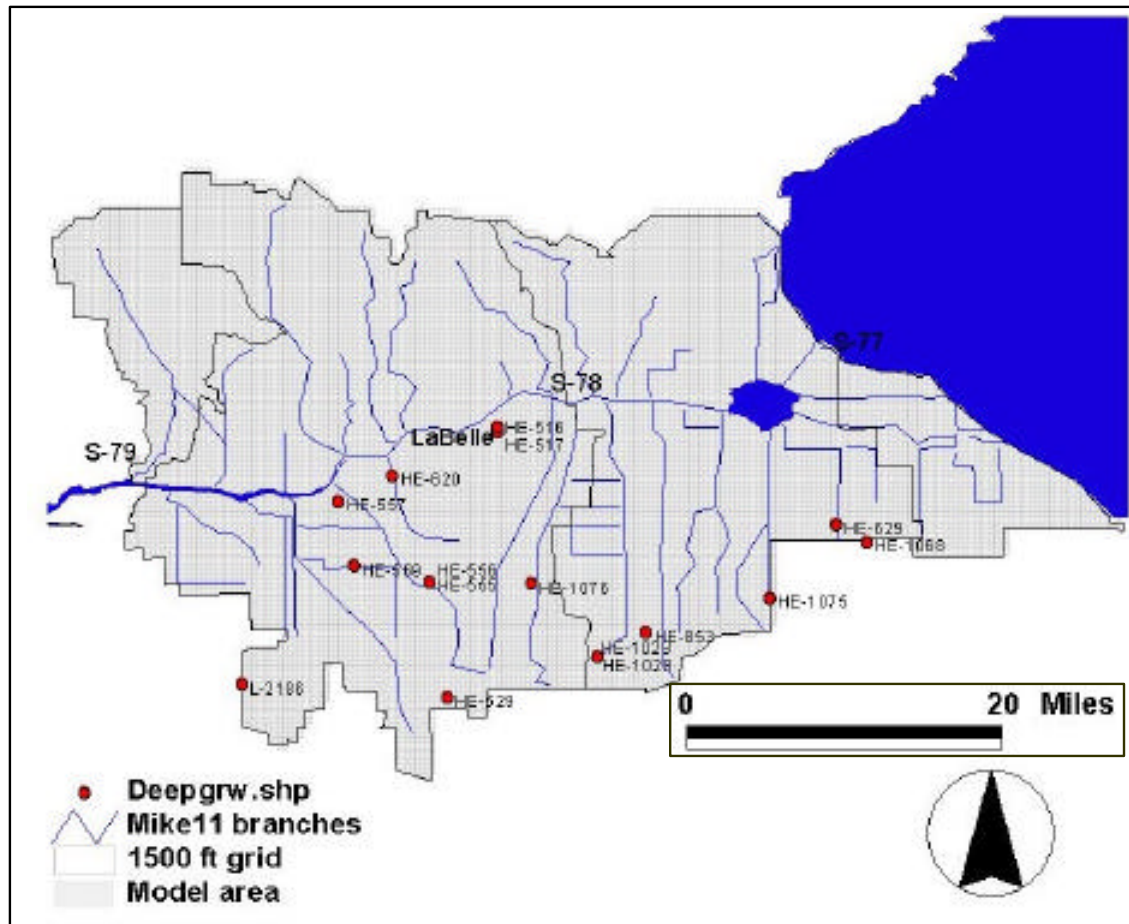
Figure G-24.   Observation Wells, Deep Aquifer.
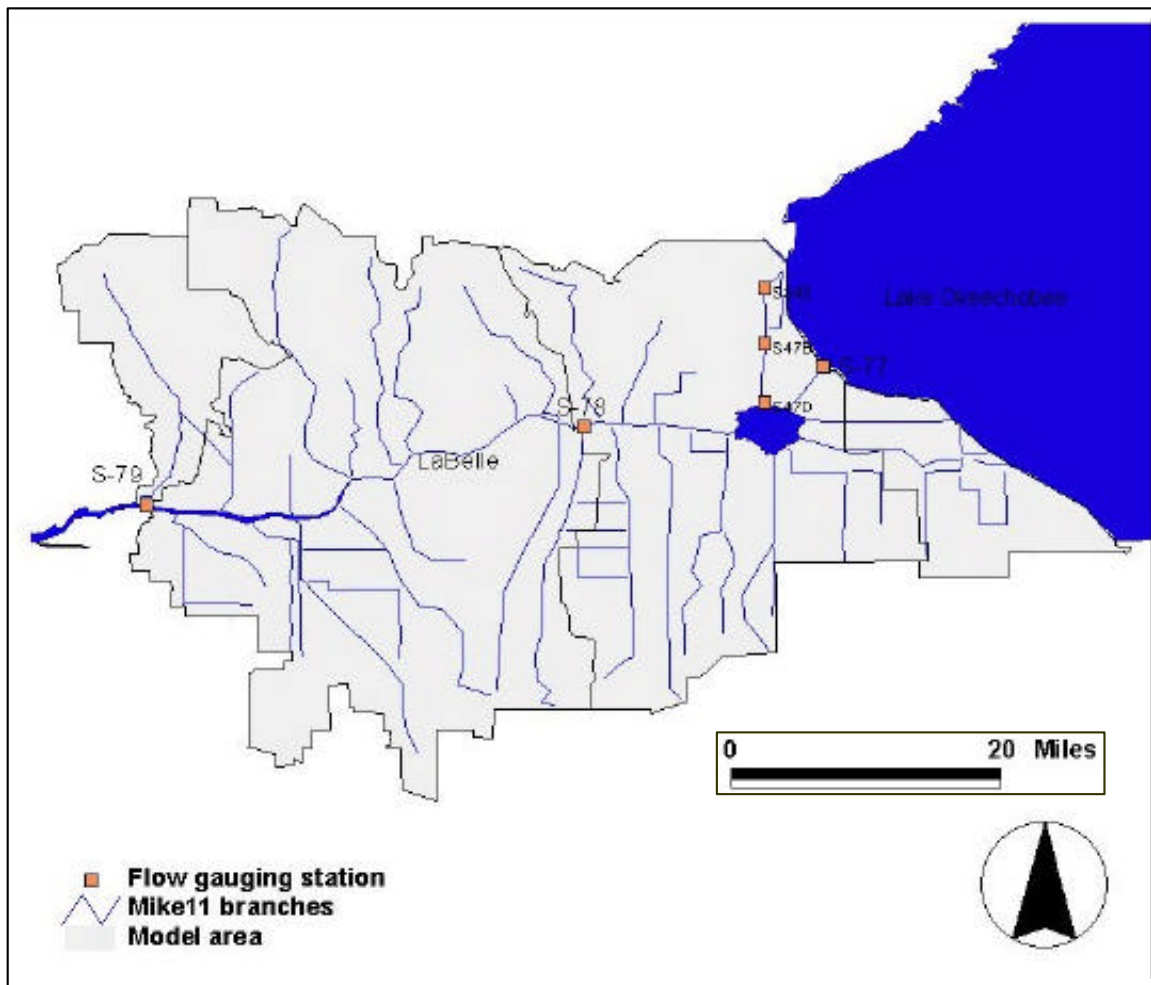
Figure G-25. Surface Flow-Gauging Stations.

Calibration Targets

The definition of a satisfactory calibration is not very clear and depends on the purpose of the model. Various criteria may be adopted to quantify the maximum tolerable deviation between observed values and simulated values. When comparing time series, statistical measures of fit between the simulated and observed variables may be introduced. It was, however, difficult to provide predefined calibration targets tailored for the specific purpose of the Caloosahatchee Basin model. In terms of water balance, the ability of the model to simulate both wet and dry period conditions is required. On the other hand, water resource problems in the basin are only seen during dry periods with high irrigation demands, implying that low flow periods should be subject to special attention. The formulated calibration targets have been based on general criteria and they were not tailored to the specific purpose of the Caloosahatchee Basin model or the availability of field data. Subsequently, they should be seen as overall guidelines.

For the ground water component of MIKE SHE, it is the objective first to simulate average ground water potential head within the simulation period. Secondly, the range of potential head (maximum and minimum levels) should be represented. Finally the model, to the extent possible, should describe the full dynamics given limitations in input data.

During the project "Developing a Small Scale Integrated Surface Water and Ground Water Model for the South Florida Hydrogeologic System" prepared for the SFWMD by DHI, a set of improved model calibration utilities were developed. The utility calculates statistical criteria for the deviation between observed and simulated time series of potential head at each observation well:

- $R1_j$: Percentage of time where the absolute value of $(RES_{i,j} - RES_{std,j})$ is less than 25 percent of $(H_{obs,max,j} - H_{obs,min,j})$

- $R2_j$: Percentage of time where $H_{sim,i,j}$ lies within the range $(H_{obs,i,j} - H_{obs,std,j}$; $H_{obs,i,j} + H_{obs,std,j})$

- $R3_j$: Percentage of time where $H_{sim,i,j}$ lies within the range $(H_{obs,min,j}$; $H_{obs,max,j})$

- $R4_j$: Percentage of time where $H_{sim,i,j}$ lies within the range $(H_{obs,i,j} - 1 \text{ ft}$; $H_{obs,i,j} + 1 \text{ ft})$

where:

N_{time}: number of observed values in a time series ($i = 1, N_{time}$)

N_{wells}: number of observation wells ($j = 1, N_{wells}$)

$H_{obs,min,j}$, $H_{obs,max,j}$, $H_{obs,std,j}$: Minimum, maximum, and standard deviation of observation time series

$RES_{i,j}$: Residual ($H_{obs,i,j} - H_{sim,i,j}$)

$RES_{std,j}$: Standard deviation on residuals

The R1, R2, R3, and R4 criteria are not universally valid statistical criteria, which will ensure a satisfactory calibration in any model set-up. They do, however, represent objective numerical criteria which may be indicative of calibration accuracy in general.

The above listed criteria were applicable to the calibration of ground water tables. For the surface water discharges, a close agreement between observed and simulated flow should be obtained in terms of dry period flows, peak flows, and accumulated runoff. The calibration targets presented in **Table G-13** were suggested for the river flows.

Table G-13. Suggested Calibration Targets for the C-43 Canal Discharge.

	Cumulative Mass Error	Standard Deviation of the Error	Average Cumulative Mass Error
West Basin Deficit	5 percent	5 days 20 percent	5 percent
		30 days 10 percent	
West Basin Excess	5 percent	5 days 35 percent	5 percent
		30 days 15 percent	
East Basin Deficit	5 percent	5 days 20 percent	5 percent
		30 days 10 percent	
West Basin Excess	5 percent	5 days 35 percent	5 percent
		30 days 15 percent	

Peak flows in the C-43 Canal may not be fully captured by the model due to the high variability in rainfall during storms compared to the density of rainfall stations and the uncertainty of readings during storms. In terms of water balance and water shortage, it was more important that the model simulated the recession in flows following discharges of large volumes of storm water and the intermediate dry periods. Dry period flows were influenced by the irrigation water demands and the control structures operated to distribute the water. Consequently, the simulated dry period flow is indicative of the balance between canal storage, canal flow contributions (ground water seepage and drainage), and irrigation diversions based on simulated water demands. Short-term fluctuations in observed daily discharge time series were attributed to operation of locks and other hydraulic control structures. Due to the limited information on actual structure regulation and the exact operational schedule the model could not represent such fluctuations. Subsequently, it was the objective of the modeling to simulate low flow as the average minimum flow within each dry period.

The requirement to simulate the accumulated flow in the main canal ensured a correct water budget for the eastern (S-78) and the western (S-79) part of the basin. Accumulated flows were evaluated for the entire simulation period.

Primary Calibration Parameters

The hydrological regime and thus the water balance of the Caloosahatchee Basin is characterized by relatively high rates of rainfall (approximately 60 inches/year (1,500 mm/year)) and evapotranspiration (pan evaporation of approximately 79 inches/year (2,000 mm/year)). Evapotranspiration is the dominant factor of the water budget with or without irrigation. The infiltration capacity of the soils is high and the net rainfall recharges the water table aquifer. The flow in the water table aquifer is in general directed toward the numerous canals and ditches. Due partly to the hydraulic contact between surface water bodies and the upper aquifer sequence and partly to the hydrologic nature of the dense drainage networks, the shallow ground water seeps into the canals.

The number of parameters and possible combinations is large for distributed models. It is thus imperative to restrict the parameters subject to modification during the calibration and to the extent possible, define ranges of the individual parameters applied to obtain a successful calibration. Within each model component, the primary parameters must be specified and parameter intervals (minimum and maximum values) are specified from measured field data, general characteristics of the model area, and experience.

Table G-14. Primary Parameters Adjusted during Calibration.

Model Component	Calibration Parameters	Parameter Range
MIKE SHE SZ – Saturated zone flow	K_h: Horizontal hydraulic conductivity K_v: Vertical hydraulic conductivity Drainage time constant	Determined from pump test transmissivity data $< K_v/K_h < 1.0$ $0.00001 - 0.001$ s^{-1}
MIKE SHE UZ – Unsaturated zone flow	pF_{fc}, Capillary pressure at field capacity n, Exponent of hydraulic conductivity curve	$1.0 < pF_{fc} < 2.0$ $5.0 < n < 20.0$
MIKE SHE ET – Evapotranspiration	Aroot : Root mass parameter K_c : Crop coefficient	0.8-1.2 0.7-1.2
MIKE SHE OC – Overland and river/canal flow (MIKE11)	M, Overland Manning number D, Detention storage L, leakage coefficient M, River/canal Manning number	1-10 m1/3/s 0.03 ft (0.01 m) 1e-3 – 1e-7 s-1 20-30 m1/3/s
MIKE SHE IRR – Irrigation module	Eact/Epot, crop water stress factor (target ratio between actual and potential evapotranspiration rates)	.90 - 1.00

Calibration Results

Calibration results are presented in **Figures G-26** through **G-31** and in **Tables G-15** and **G-16**.

Table G-15. Statistical Calibration Criteria, Shallow Aquifer (1986-1990).

Well ID	Record Number	Number of Observations	Observed Minimum (m)	Observed Maximum (m)	R1 (%)	R2 (%)	R3 (%)	R4 (%)
HE-1027	1	25	7.88	9.06	96.0	60.0	92.0	48.0
HE-1077	9	23	7.16	8.42	82.6	47.8	73.9	47.8
HE-858	16	38	5.63	6.63	23.7	5.3	18.4	13.2
HE-857	17	48	4.03	5.16	68.8	45.8	87.5	41.7
HE-852	21	38	7.70	8.74	52.6	18.4	57.9	31.6
HE-851	22	62	6.95	9.03	98.4	79.0	100.0	64.5
HE-569	23	49	6.35	7.39	81.2	39.8	71.4	63.1
HE-558	24	639	4.35	5.09	13.9	23.5	0.0	0.0
HE-554	25	48	8.55	10.13	89.6	52.1	87.5	58.0
L-727	29	1,435	3.96	5.39	24.4	8.1	11.7	7.8
L-1137	31	1,441	4.87	6.63	93.7	61.4	89.2	48.3

Table G-16. Statistical Calibration Criteria, Deep Aquifer (1986-1990).

Well ID	Record Number	Number of Observations	Observed Minimum (m)	Observed Maximum (m)	R1 (%)	R2 (%)	R3 (%)	R4 (%)
HE-516	1	37	2.17	4.06	97.3	75.7	100.0	48.6
HE-517	2	1,441	2.33	4.2	81.3	29.2	100.0	25.5
HE-555	4	61	4.11	7.99	67.2	59.0	100.0	34.4
HE-556	5	1,431	1.99	7.82	94.1	67.6	100.0	27.8
HE-557	6	48	2.15	4.81	95.8	72.9	100.0	33.3
HE-559	8	48	5.11	6.65	58.3	18.8	43.8	12.5
HE-560	9	50	5.87	6.92	84.0	56.0	100.0	64.0
HE-620	10	46	3.19	5.01	58.7	34.8	91.3	30.4
HE-629	11	48	4.9	5.91	16.3	12.5	33.3	14.6
HE-853	12	38	7.53	9.24	36.8	5.3	21.1	2.6
HE-1028	13	25	7.87	8.99	84.0	56.0	80.0	48.0
HE-1029	14	25	7.87	9.03	84.0	56.0	80.0	48.0
HE-1076	17	22	5.3	7.79	77.3	40.9	81.8	28.2
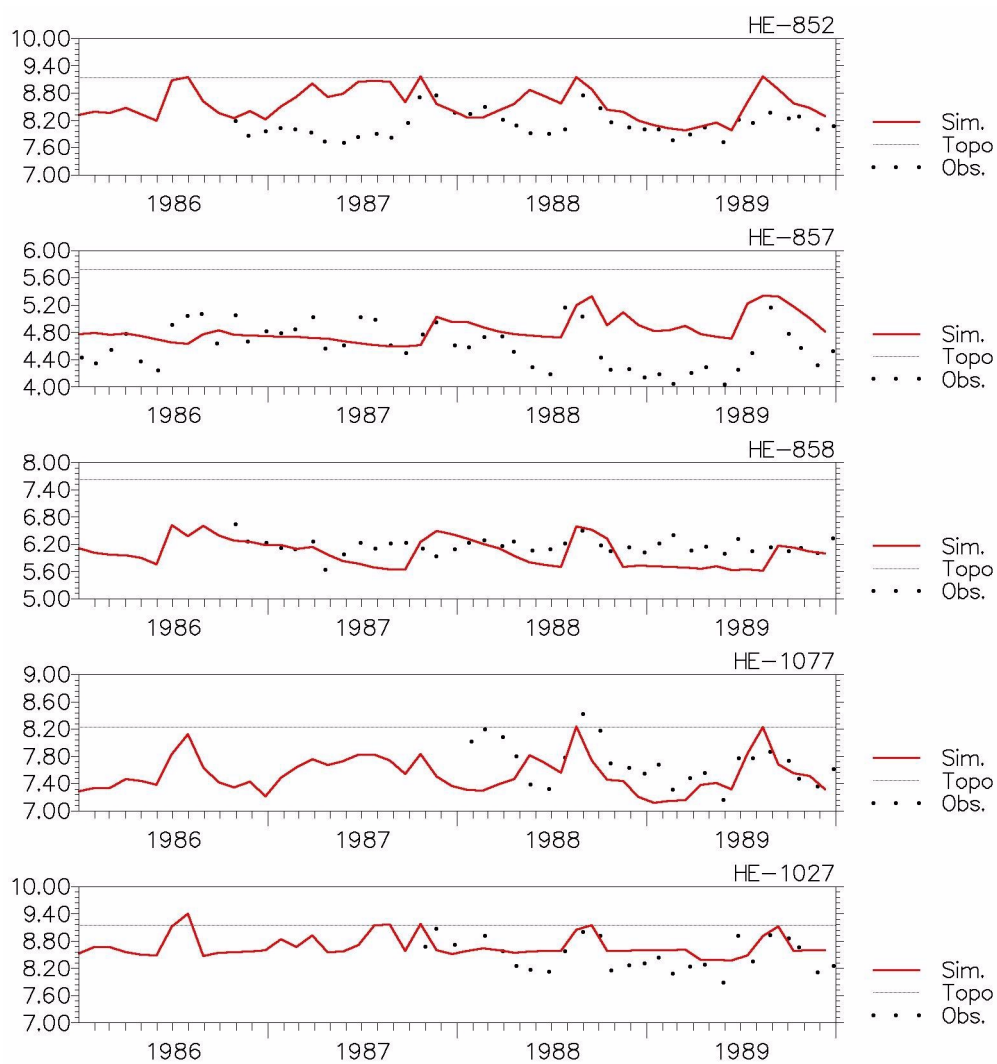
Figure G-26. Simulated and Observed Potential Head in Shallow Aquifer, 1986-1990.
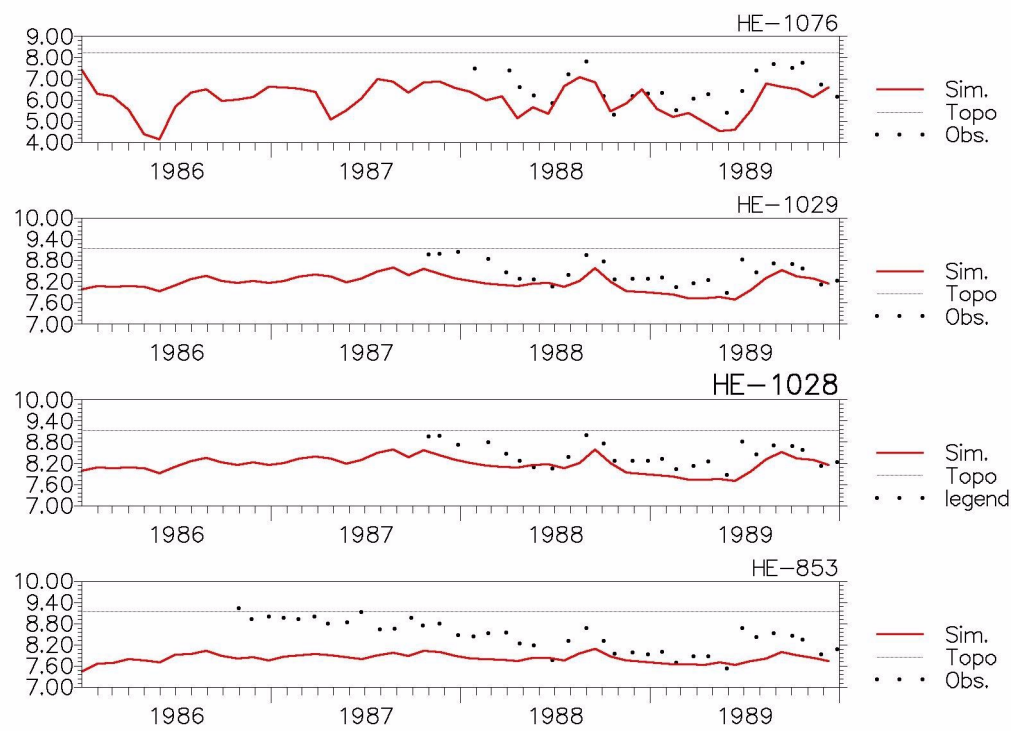
Figure G-27. Simulated and Observed Potential Head in Deep Aquifer, 1986-1990.
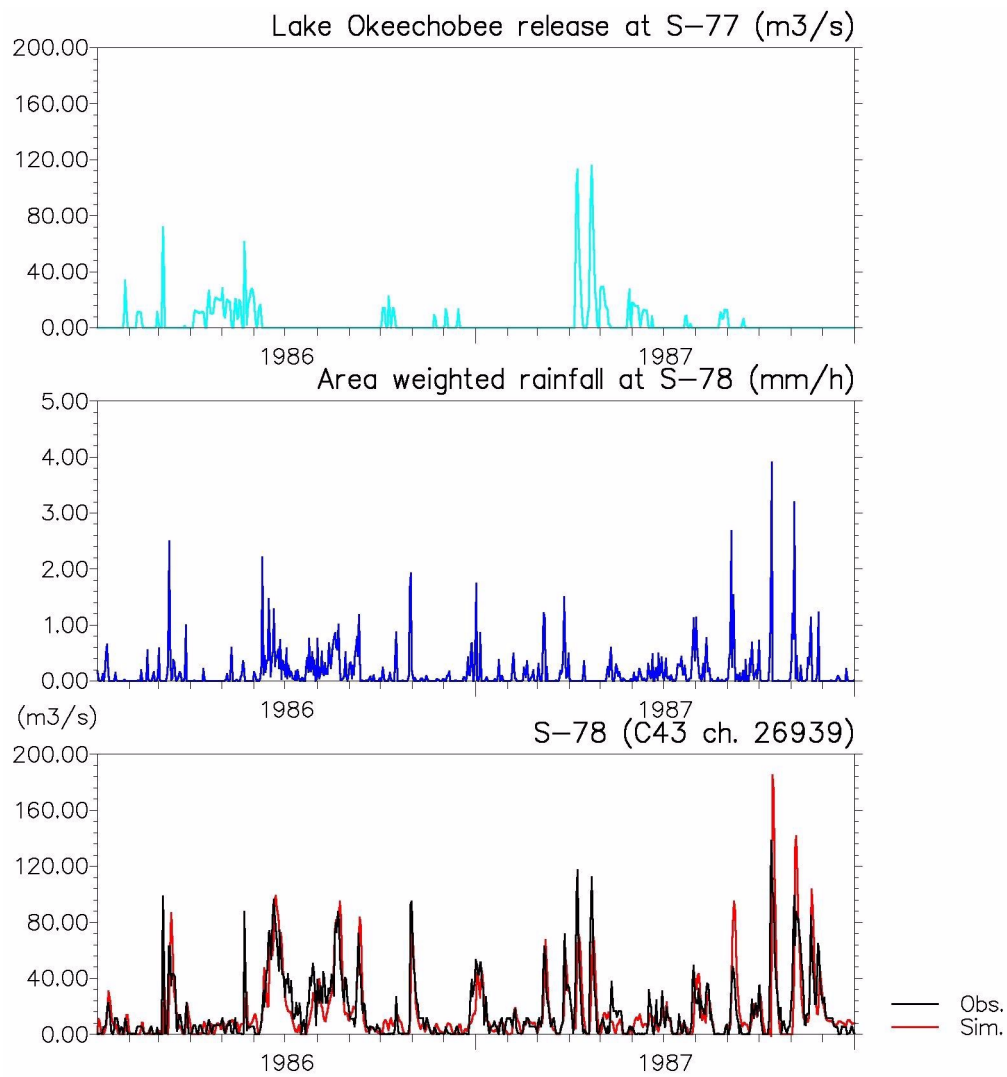
Figure G-28. Simulated and Observed Canal Flow (S-78), 1986-1988

Figure G-29. Simulated and Observed Canal Flow (S-78), 1988-1990.

Figure G-30. Accumulated Surface Discharge, 1986-1990.
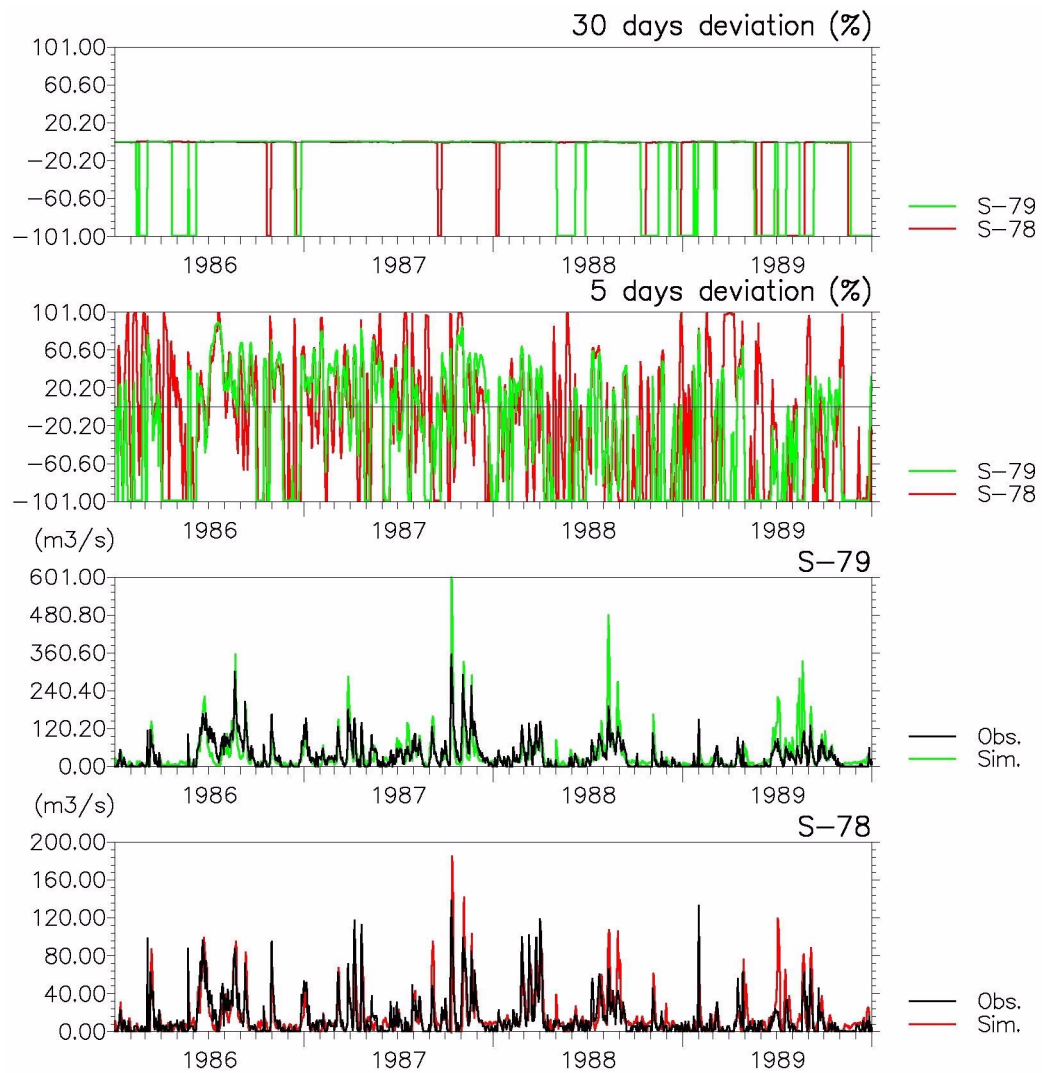
Figure G-31. Statistical Calibration Criteria, C-43 Discharge.

Validation

The period 1994-1998 was chosen for model validation. All parameters applied in the calibration were unchanged during validation. Significant changes in land use and an increase in irrigated area must, however, be incorporated to properly represent the field conditions. The validation of the model can be used to investigate if the model parameters applied in the calibration period may be considered valid for the entire period 1986-1998. The model is capable of simulating the ongoing land use change in the basin. The irrigation canal network and ground water wells locations are assumed identical for the two calibration periods implying that the irrigation canal system, but not necessarily the irrigation water demand, is unchanged.

Due to incomplete rainfall data for the period 1996-1998, the validation only covers the period 1994-1996. Validation results are presented in **Figures G-37** through **G-45** and in **Tables G-17** and **G-18**.
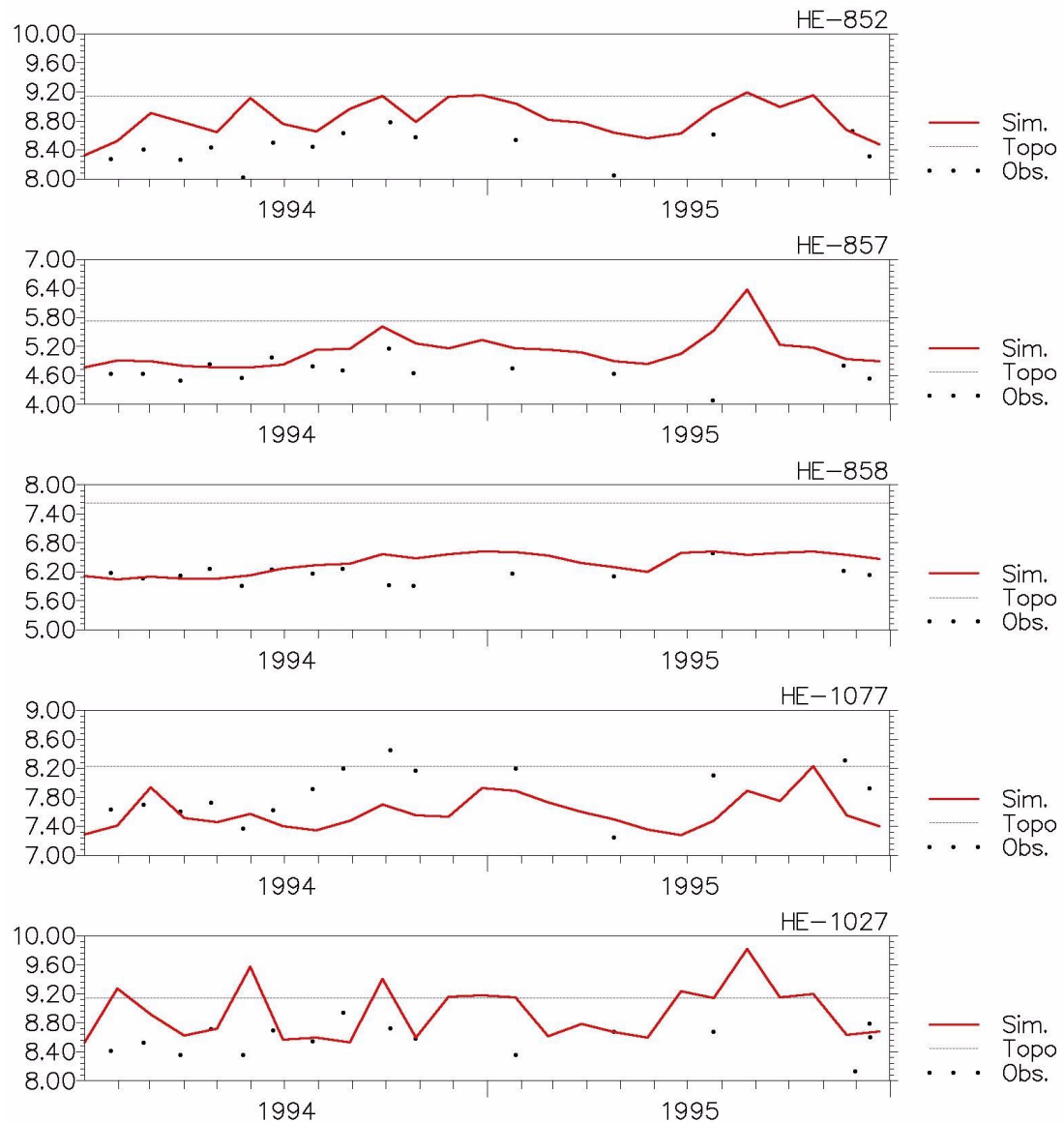
Figure G-32. Simulated and Observed Potential Head (Shallow Aquifer), 1994-1996 Validation.
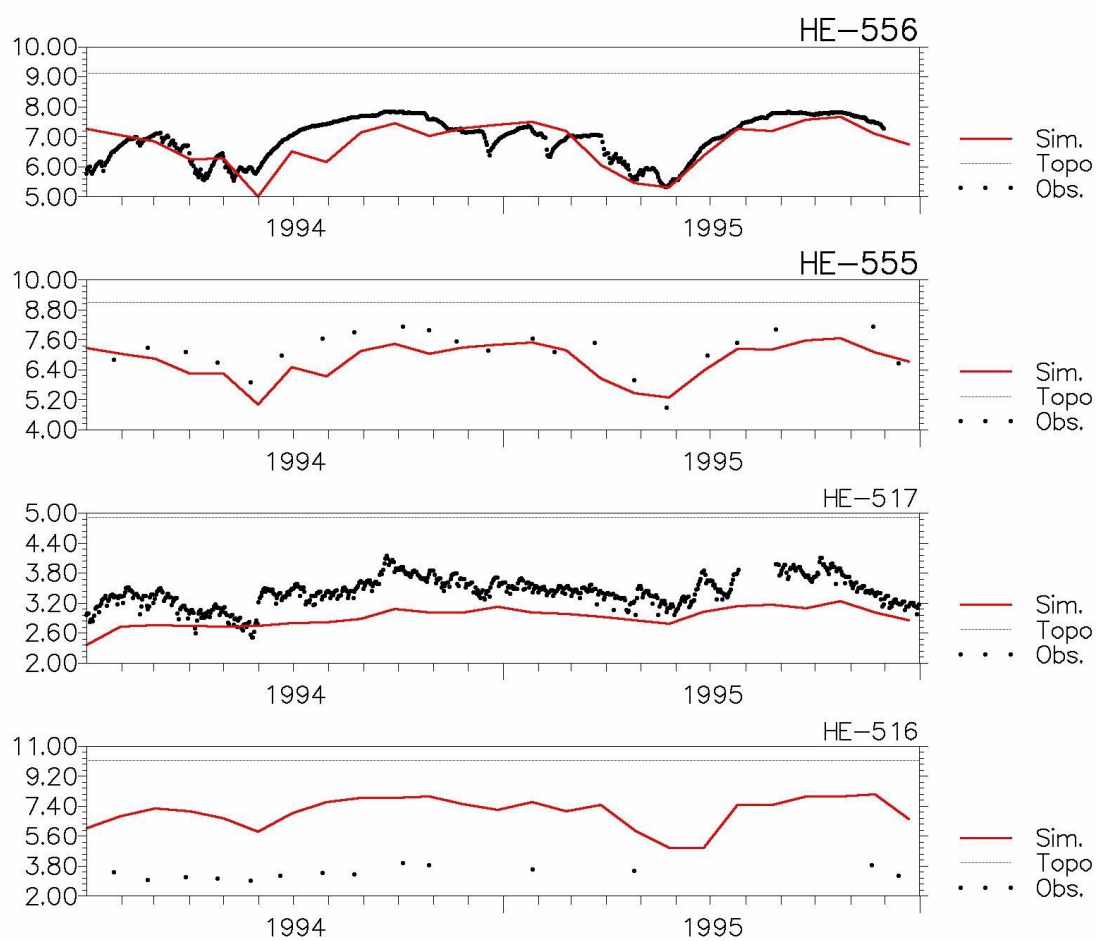
Figure G-33. Simulated and Observed Potential Head In Deep Aquifer, 1994-1996 Validation.
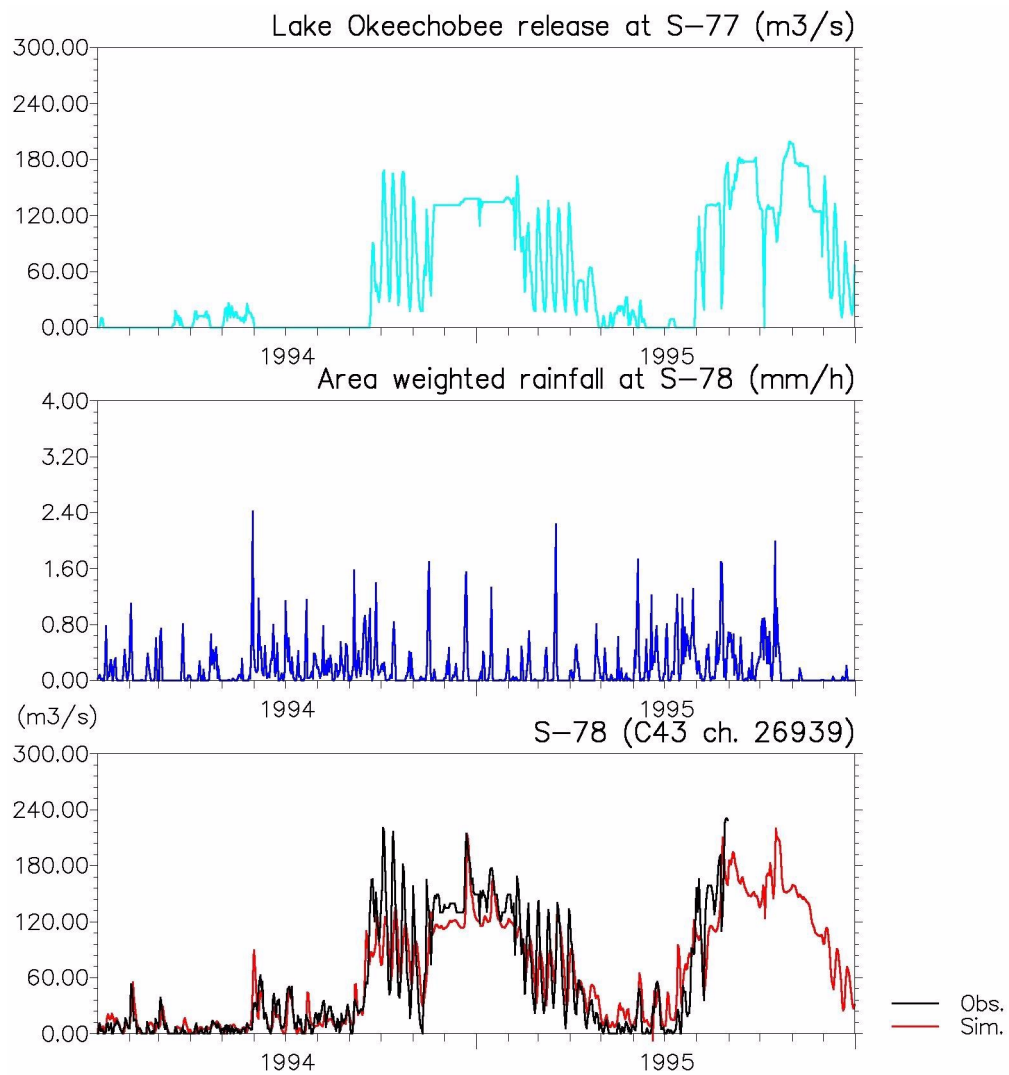
Figure G-34. Simulated and Observed Flow (S-78), 1994-1996.
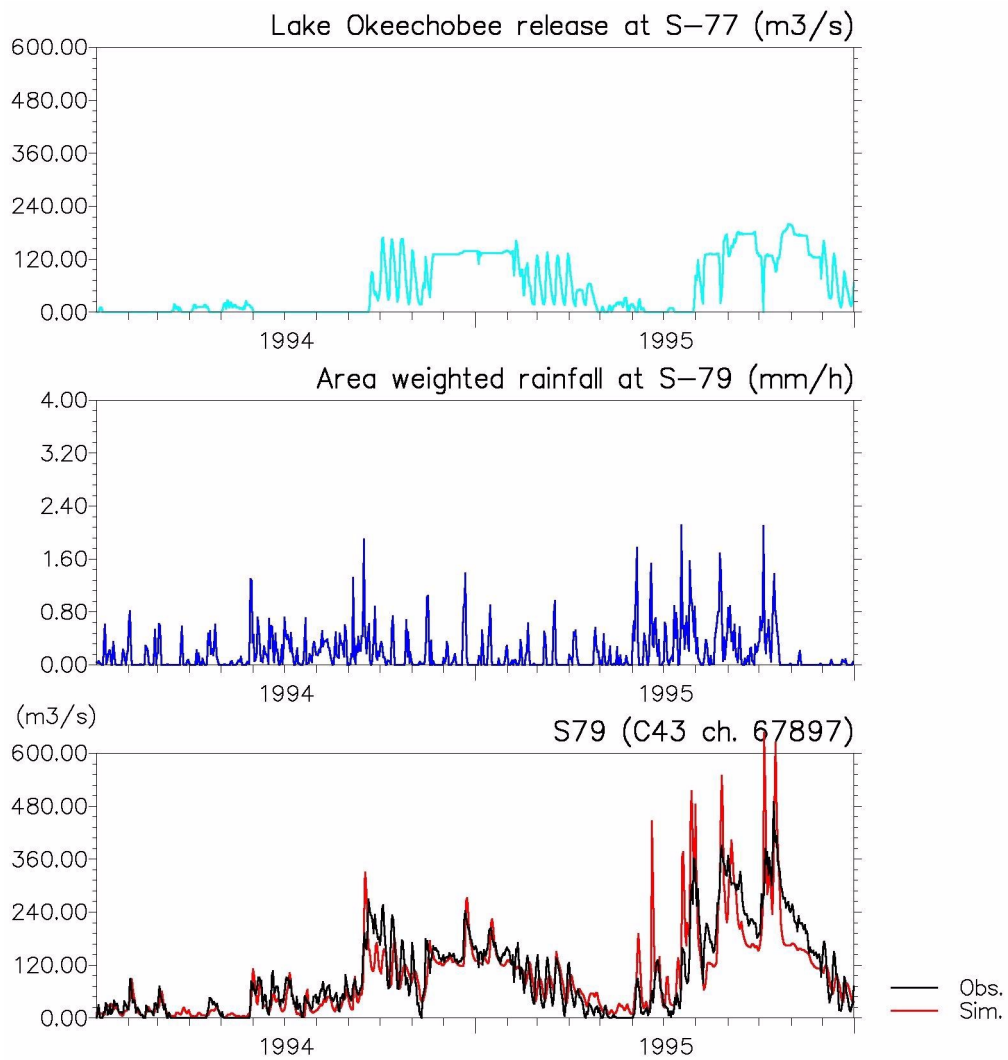
Figure G-35. Simulated and Observed Flow (S-79), 1994-1996.
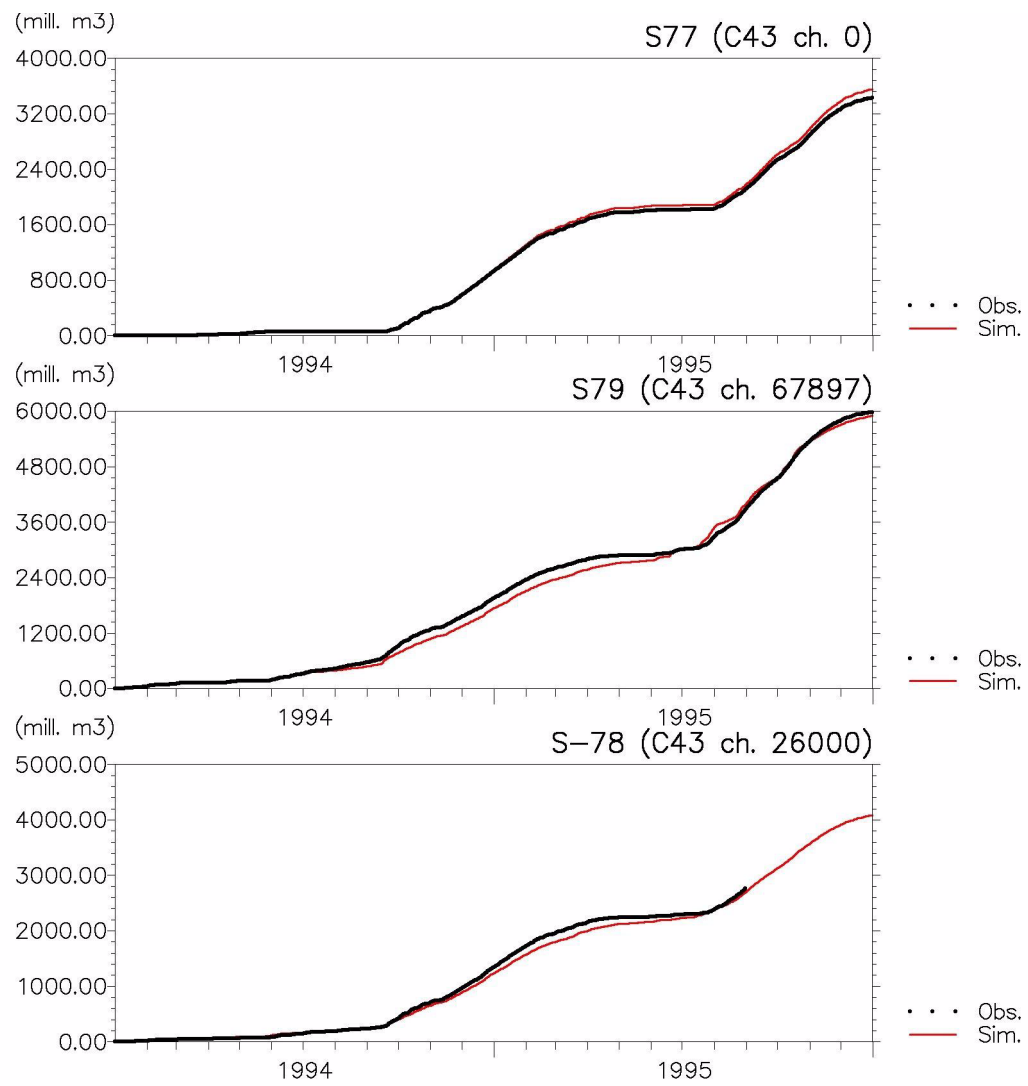
Figure G-36. Simulated and Observed Accumulated Discharge, 1994-1996.

Table G-17. Statistical Calibration Criteria, Shallow Aquifer (Validation).

Well ID	Record #	Number of Observations	Observed Minimum (m)	Observed Maximum (m)	R1 (%)	R2 (%)	R3 (%)	R4 (%)
HE-1027	1	16	8.13	8.93	31.3	43.8	81.3	56.3
HE-1077	9	15	7.24	8.45	86.7	53.3	100.0	46.7
HE-858	16	15	5.90	6.58	53.3	13.3	26.7	33.3
HE-857	17	15	4.08	5.15	73.3	40.0	73.3	53.3
HE-852	21	15	8.01	8.78	73.3	33.3	60.0	46.7
HE-851	22	22	7.67	9.13	63.6	50.0	95.5	50.0
HE-569	23	16	6.70	7.36	18.8	43.8	68.8	56.3
HE-554	25	14	8.27	9.77	78.6	57.1	100.0	42.9
L-727	29	715	4.00	5.52	54.0	28.0	35.5	24.2
L-1137	31	679	4.92	6.77	81.7	48.7	66.7	34.9

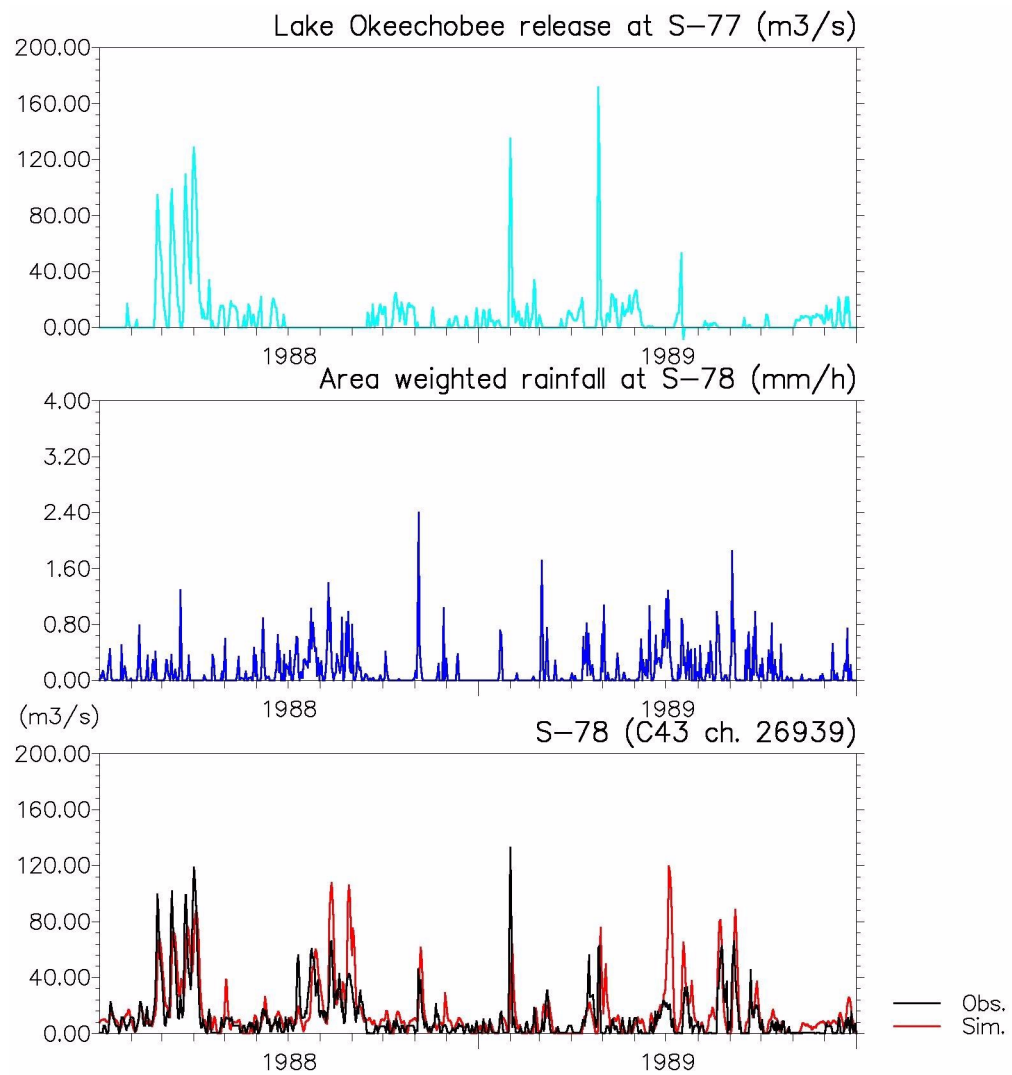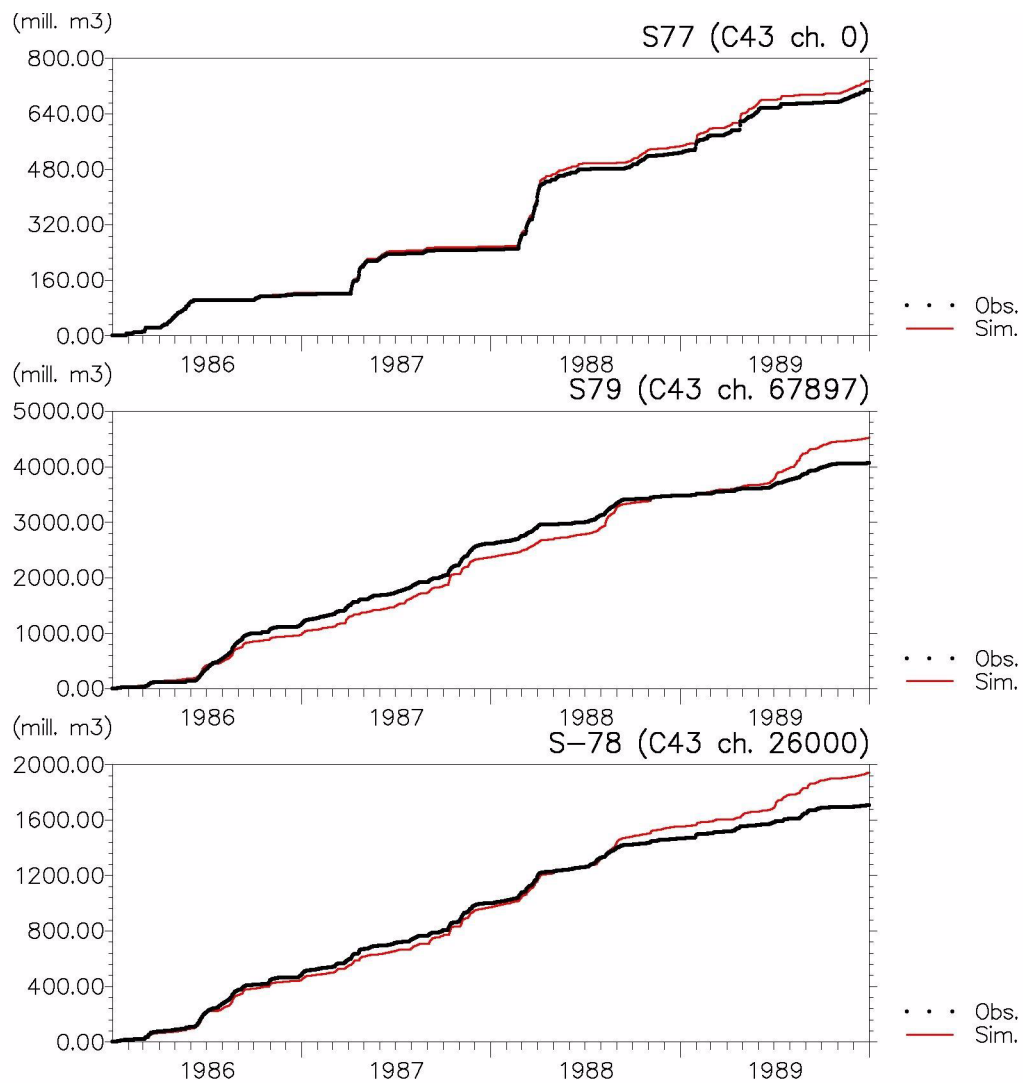**Table G-18.** Statistical Calibration Criteria, Deep Aquifer (Validation).

Well ID	Record #	Number of Observations	Observed Minimum (m)	Observed Maximum (m)	R1 (%)	R2 (%)	R3 (%)	R4 (%)
HE-516	1	14	2.90	3.98	78.6	57.1	92.9	57.1
HE-517	2	689	2.50	4.14	73.3	17.1	98.4	18.0
HE-555	4	22	4.11	7.99	90.9	77.3	100.0	31.8
HE-556	5	1,431	1.99	7.82	95.7	78.3	98.3	40.5
HE-557	6	15	3.20	4.72	100.0	46.7	100.0	26.7
HE-559	8	16	5.18	6.61	62.5	75.0	68.8	43.8
HE-560	9	16	5.73	6.82	37.6	62.5	62.5	56.3
HE-620	10	22	3.51	5.01	45.5	22.7	63.6	22.9
HE-629	11	15	4.82	5.75	26.7	19.4	52.1	18.3
HE-853	12	22	7.25	8.53	8.4	13.5	31.6	17.8
HE-1028	13	46	8.21	8.94	46.7	16.7	26.7	6.7
HE-1029	14	46	8.18	8.92	43.8	18.8	31.3	37.5
HE-1076	17	61	6.54	8.51	50.0	21.4	57.1	14.3

Model Uncertainty

A numerical model is associated with a certain level of uncertainty. It is desirable to quantify the uncertainty in order to interpret model results in a wider context as part of water management. In an integrated and distributed model, it is difficult to assess the effect of single inputs or parameters on the different results from the model. Uncertainty should be regarded as specific to a certain output of the model (e.g., discharge or ground water tables at a given location).

The deviations between simulated and observed variables indicate uncertainties in both input data and model parameters, which must be considered when interpreting model results. To minimize uncertainty, comparisons between effects of various water management scenarios should be conducted in terms of relative changes rather than absolute values. When interpreting the model results of a scenario relative to a base scenario (i.e. the difference between two sets of simulation results), the uncertainty originating from the approximate agreement between calibrated model results and field data, is minimized.

Sensitivity Analysis

The purpose of a sensitivity analysis is to determine model parameters and model inputs, which are of primary importance to the model results. Input data or parameters, which are considered crucial to the model results, may be varied to quantify their effect on specific model results. By carrying out a series of model runs varying the parameter or input data within given ranges a general overview of the models sensitivity is established. If the model results are particularly sensitive to a specific parameter or input type the model results should accordingly be interpreted with the uncertainty associated with this particular parameter.

The Caloosahatchee Basin ISGM was applied to estimate the water budget and the stress on the resource caused by irrigation. Looking at the overall water balance, it was clear that evapotranspiration accounts for the largest water loss from the model area. It was thus essential to simulate the actual evapotranspiration. Accurate calculation of actual evapotranspiration depended both on the input data and the model parameters.

Conclusions

The Caloosahatchee Basin ISGM was calibrated and validated against time series of observed potential head and the C-43 Canal discharge at S-78 and S-79. The ground water observation wells are all located in the southern part of the model area. The discharge at S-78 includes the runoff from the eastern part of the basin and S-79 includes runoff from the entire model area.

The simulated C-43 Canal flow at S-78 is close to measurements with respect to low flow, accumulated runoff, and peak flows. At S-79, the low flow simulated by the model is generally over estimated. The absolute deviation is between 0 to 10 m^3/s, while the relative deviation may be high during dry periods when the measured flow approaches zero. The relative measures (accumulated for five days and 30 days respectively) show that dry period flow deviation fluctuates. The highest relative deviations are higher than the calibration targets. It may be indicative of not only calibration accuracy but also uncertainty in low flow measurements applying rating curves. The canal flow calibration criteria based on relative deviation should be considered in connection with the absolute differences.

The model describes the increase and subsequent recession in river flow, but the absolute peak level is either underestimated or more often overestimated at some rainfall events. This is, however, partly attributed to limitations in input data and apparently too high drainage flow at some storm events. Comparing rainfall, Lake Okeechobee releases, and the measured river flows, it is observed that high river flows are apparently not always driven by rainfall and boundary inflow. This indicates that the rainfall station network may not be sufficient to describe all events or that the flow measurement is not complete.

During parts of the calibration period the simulated hydrographs at S-78 and S-79 are very close to the observed. The model describes very accurately the basin runoff (1986, 1987, and partly 1988). For other periods, clear deviations are seen. With the applied set of parameters, the model is thus capable of capturing runoff for the simulation period in general, while deviations are observed for shorter durations. Further adjustment of parameters to simulate single storm events may thus have adverse effects for the remaining part of the period.

No data exist to describe gradual changes in the basin (e.g., canal network or land use) during the simulation period. The effects of ongoing changes cannot be addressed as part of calibration.

The simulated ground water potential heads of the shallow aquifer correspond very well to the observed time series with respect to average ground water level. The dynamics is not entirely captured by the model at all observation well locations. This applies especially to some observation wells in the deep aquifer. One reason for the lack of water table fluctuation is drainage. Drainage levels are specified for areas assumed drained. When the ground water table rises above the drainage level, the ground water volume is routed to receiving points in the basin. Receiving points could be depressions, wetlands, or canals. Consequently, the drainage level reduces the maximum level of the ground water table.

Figure G-37 shows observed and simulated potential heads at two locations where observations exist for both aquifers. The deep aquifer is more dynamic than the shallow aquifer. The most likely reason for the head fluctuations in the deep aquifer is drawdown from nearby wells. The low potential heads do not seem to affect the head of the shallow aquifer, which indicates that the vertical hydraulic conductivity is very low. As withdrawal data for individual wells are not available, it is not possible to simulate the local drawdowns. The examples show that the simulation of deep aquifer head fluctuations can only be simulated by including individual wells and withdrawal rates in the model, and not by further calibration of hydraulic properties.

The average level of simulated deep ground water potential heads corresponds to observed levels with the exception of two locations, where the deviation is more than five feet. The deeper ground water table is less dynamic than the shallow ground water table and the model generally simulates the maximum and minimum levels accurately. The dynamics is underestimated at a few locations. The statistical criteria show that some wells do not meet all the calibration targets (R1 - R4 to be satisfied for 75 percent of the
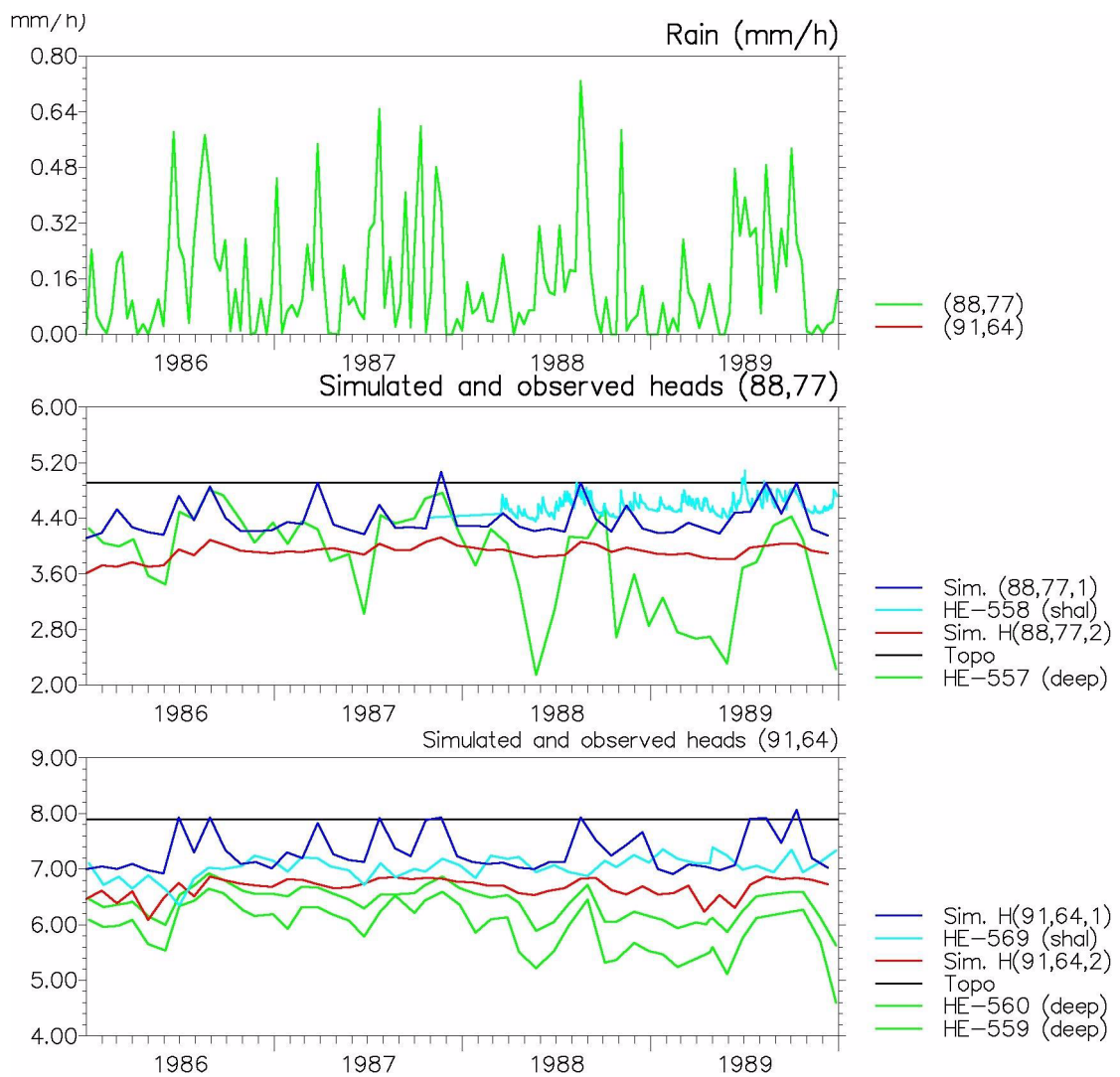
Figure G-37. Comparison of Potential Heads in Shallow and Deep Aquifer (m).

simulation period). The R4 criteria is not met for the wells in general, even at wells where a visual evaluation of the simulated and observed values suggest a close agreement.

The validation period serves to establish whether the model parameters derived during calibration are generally valid. Due to significant changes in cropped areas the land use and irrigation set-up must be modified from the calibration to the validation. The validation period is compared to the calibration period characterized by more frequent releases of water from Lake Okeechobee. The changes will test the versatility of model parameters given different conditions.

As for the calibration period, the river discharge is occasionally underestimated at peak flows while the dry period flow is simulated to the highest attainable level. No alteration in ground water levels is seen and the model simulates the average level and partly the dynamics at most shallow aquifer observation wells. The difference between simulated and observed time series of potential head in the deep aquifer varies. A close agreement is found at some locations while significant deviation is found at others.

No systematic changes in the simulated values compared to observed values are found, which indicate that the calibration parameters may be assumed valid for other periods, including future predictions.

The success of model calibration must be seen in connection with the uncertainties in input data. When formulating the targeted maximum deviation, it must be compared to the uncertainty in input and calibration data and the complexity of the hydrological system.

Given the available field data and the general basin characteristics, the calibration and validation is considered satisfactory. The calibration reflects that priority was given to simulate the surface domain and the upper part of the aquifer system with emphasis on dry period conditions.

To minimize the uncertainty of model simulations in relation to impact analysis, it is recommended that model results are interpreted in terms of changes relative to a base case scenario.

MODEL RESULTS

Water Balance

Total Water Balance

The water balance is an essential result of the modeling. It provides information on available resources and demands in the basin.

Overall water balance figures covering the entire basin and several years of simulation may not properly describe the large temporal and spatial variations in water availability and demand.

Consequently, the flow and storage in the surface water and ground water is insufficient to meet the demand and water is released from Lake Okeechobee. To reduce the need for Lake Okeechobee water, it is necessary to store an additional water volume and make it available for irrigation.

MIKE SHE incorporates both surface and subsurface flow and a total water balance for the Caloosahatchee Basin may be extracted from the simulation results. Water balance may be extracted for: the following:

- The entire basin or subbasins

- The entire simulation period or any period within it

- A total water balance including all model components or specific components (e.g., ground water)

The water balance for the entire basin or subbasins can be formulated as follows:

$$P - E = (Q_{S,out} - Q_{S,Okee}) + (Q_{G,out} - Q_{G,in}) + DS + R$$

where:

P is rainfall, E is evapotranspiration, $Q_{S,Okee}$ is surface water inflow (release from Lake Okeechobee into the C-43 Canal), $Q_{S,out}$ is Surface water flow out of the model area (Okeechobee release and basin runoff), $Q_{G,in}$ is ground water flow into the model area, $Q_{G,out}$ is ground water flow out of the model area, DS is the change in storage of surface water, unsaturated zone and ground water ($DS_s + DS_{uz} + DS_{sz}$), and R is the external sink/ sources (e.g., irrigation water supplied directly from outside the model area).

Irrigation is not added as a sink-term in the above equation. Water diverted from canals or abstracted from the ground water is used internally and will add to the actual rate of evapotranspiration. Additional water losses due to irrigation will thus be represented by a higher evapotranspiration in the total water balance.

What is of particular interest in the Caloosahatchee Basin model, is the proportion of water discharged at S-79 originating from Lake Okeechobee and from basin runoff, respectively.

The water balance for the calibration period 1986-1990 shows that evapotranspiration losses account for approximately 90 percent of the rainfall in the basin. There is a net outflow from both river and ground water. The storage change from wet to dry years is quite small. Despite the use of irrigation water, there is an additional storage available every year.

Table G-19. Total Water Balance for the Calibration Period, 1986-1990 (inches, mm).

Year	P	E	$Q_{S\ out} - Q_{S\ Okee}$	$Q_{G\ out} - Q_{G\ in}$	DS+R
1986	51 (1,286)	47 (1,190)	3 (79)	1 (19)	0 (-2)
1987	60 (1,512)	48 (1,213)	9 (238)	1 (14)	2 (47)
1988	49 (1,232)	47 (1,182)	2 (43)	1 (15)	0 (-8)
1989	48 (1,228)	44 (1,130)	4 (89)	1 (14)	0 (-5)
Total	208 (5,258)	186 (4,715)	18 (448)	3 (62)	1 (32)

Annual water balances may be supplemented by water balances for shorter periods focusing on dry conditions.

Canal Water Balance

The river discharge is the sum of the upstream flow boundary at S-77 and the basin runoff. The basin runoff is separated into three individual terms describing the exchange with aquifers, overland sheetflow and ground water drain flow. Ground water drainage is the dominant contribution during wet periods and it determines the peak flows. The seepage into the river from the aquifers is controlled by the water level gradient. Consequently, the baseflow is almost constant at normal river water levels. During storms the aquifer is recharged when the river water level rises. The overland sheetflow contribution is insignificant and is only seen at storms.

Irrigation

Irrigation demand and supply was calculated for each computational node of the irrigated areas. Results may be extracted either as time series for each irrigated grid or as maps for the entire model area at a given date.

Total Basin Irrigation

The simulated irrigation demand may be retrieved as time series for the individual computational cells or as a total for all irrigated land (**Figure G-38**).

The irrigation demand is clearly controlled by rainfall and evapotranspiration (**Table G-20**). The demand increases significantly in dry periods and approximately equals the potential evapotranspiration rate. As the demand is directly linked to the soil water content, infiltration following rainfall events causes a decrease in irrigation demand.

External sources include water pumped directly from Lake Okeechobee or ground water withdrawn from deep aquifers not represented in the model (Floridan aquifer).

If the supply from canals, wells and external sources is summed up it is slightly less than the total demand, which is an indication of shortage during the simulation period.
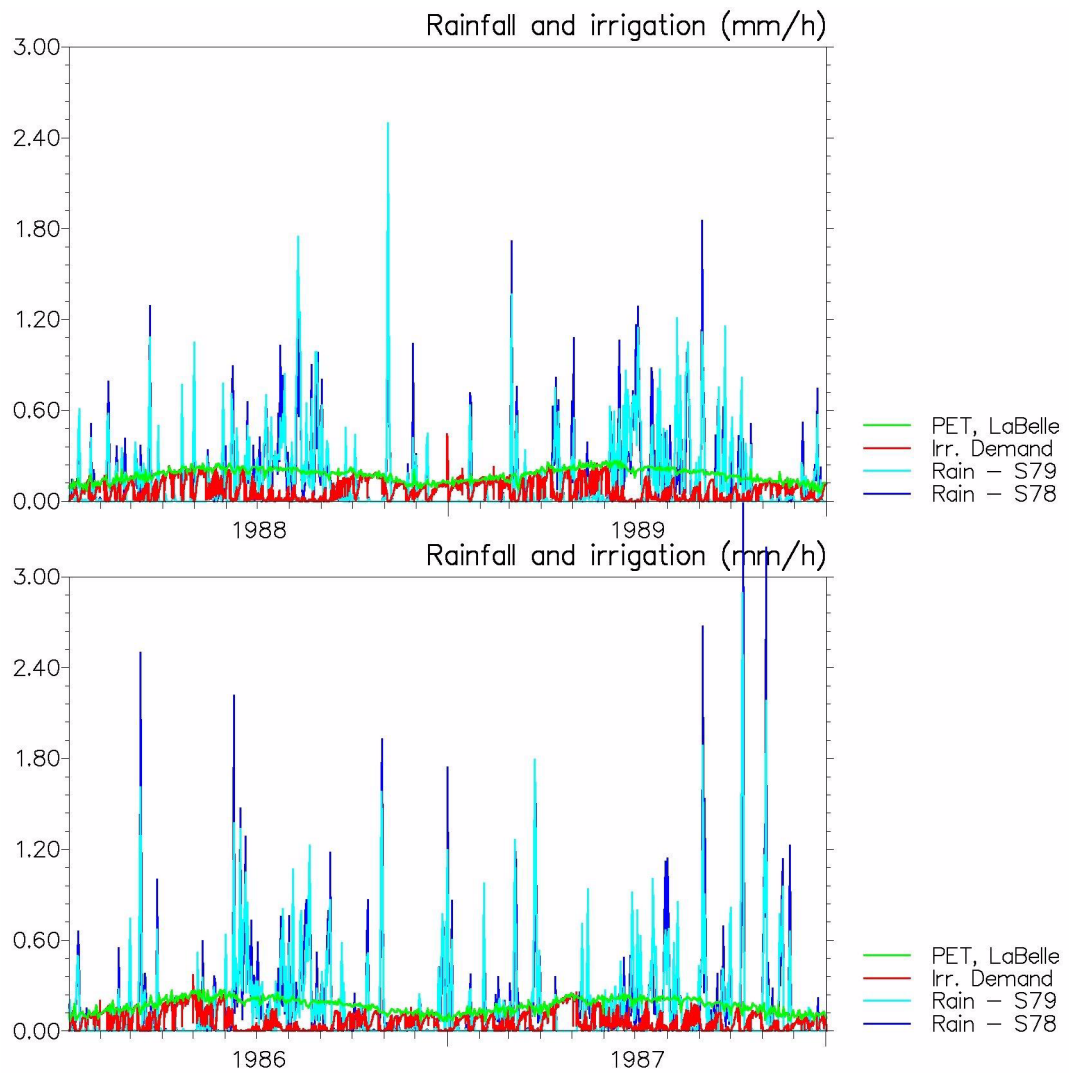
Figure G-38. Time Series of Total Irrigation Demand, Rainfall and Potential Et, (1986-1990)

Table G-20. Summary of Simulated Hydrology on Irrigated Areas, 1986-1990.

Crop	Rainfall [inches] [(mm)]	Potential ET [inches] [(mm)]	Actual ET [inches] [(mm)]	Irrigation Water Demand [inches] [(mm)]	Irrigation Canal Supply [inches] [(mm)]	Irrigation GW Supply [inches] [(mm)]	External Supply [inches] [(mm)]
Citrus	211 (5,356)	232 (5,888)	222 (5,650)	138 (3,504)	67 (1,698)	65 (1,653)	0 (0)
Sugarcane	188 (4,787)	226 (5,742)	216 (5,491)	128 (3,890)	110 (2,803)	0 (0)	15 (382)
Truck Crops	199 (5,066)	232 (5,904)	228 (5,781)	145 (3,679)	91 (2,312)	48 (1,226)	4 (98)

Shortage is not a common phenomenon in the Caloosahatchee Basin model and occurs only in restricted areas for short periods of time.

The distributed mean actual evapotranspiration for the Caloosahatchee Basin model shows a clear increase in areas which are irrigated (**Figure G-39**). In wet nonirrigated areas (e.g., Telegraph Creek Catchment in the northwestern part of the model area), the rates are kept higher due to free water surface evaporation and higher root zone soil water content.

Field Scale Irrigation

The irrigation module simulates irrigation demand, irrigation supply, unsaturated zone flow, and ground water recharge in every grid cell in the model (**Figure G-40**). Depending on the land use and the local conditions, the irrigation supply varies in both time and space.

Irrigation Demand and Canal Discharge

The canal discharges and water levels are affected by the allocation of water for irrigation. The dry period flow at S-79 clearly shows the effect of diversions to the irrigation canals. The volume released from Lake Okeechobee in dry periods is gradually used for irrigation as it flows through the C-43 Canal.

CONCLUSIONS

A highly advanced and comprehensive integrated hydrological model was developed for the Caloosahatchee Basin based on the MIKE SHE modeling system. The model includes subsurface flow in terms of ground water and unsaturated zone flow, surface water in terms of overland and canal flow, and a fully dynamic coupling between the components of the model. Furthermore, a fully distributed irrigation module was applied linking irrigated land and irrigation sources in the basin. Meteorological data, topographical data, soil physical data, land cover data, vegetation data, hydrogeological
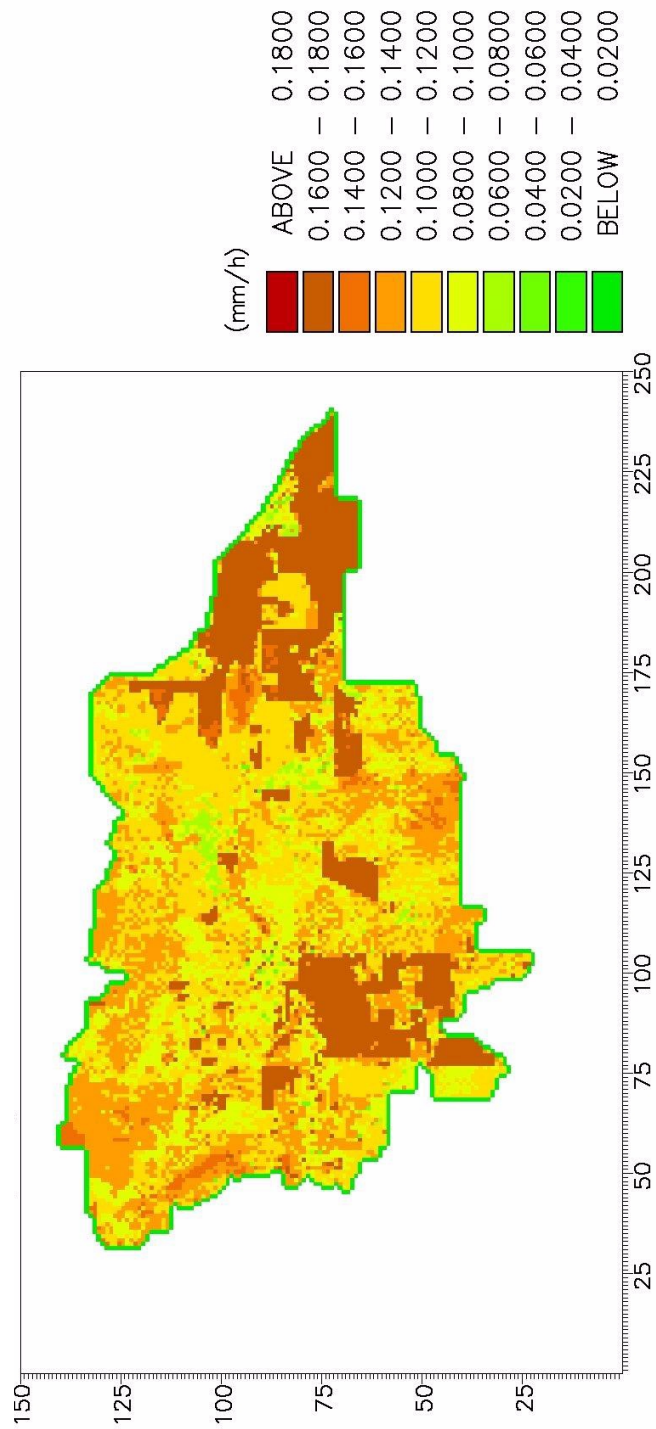
Figure G-39. Simulated Mean Actual Evapotranspiration, 1986-1990.
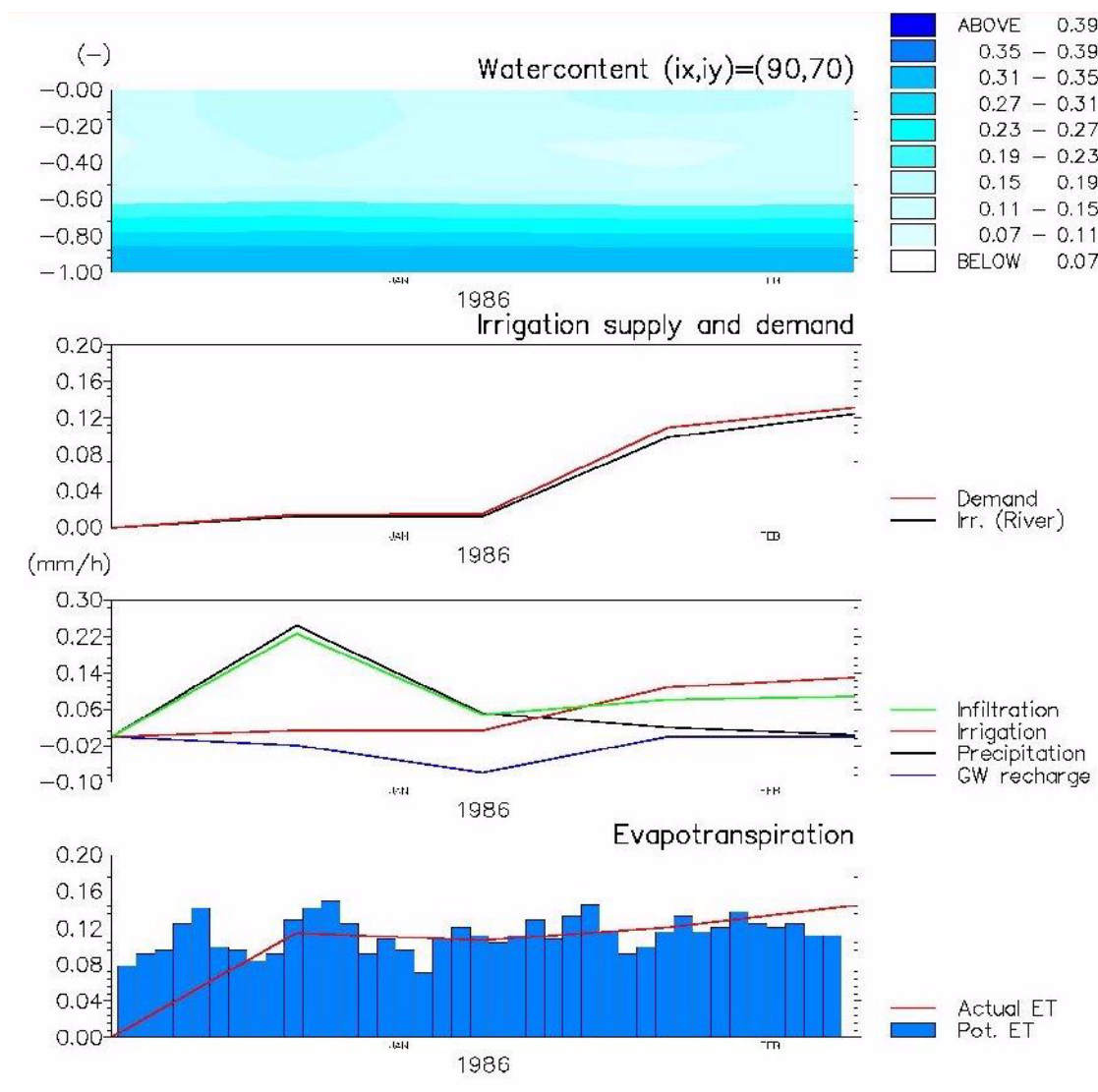
Figure G-40. Irrigation and ET in Irrigated (Citrus) Area.

data, canal and hydraulic structure data, and irrigation permit data were used to establish the model.

The hydrology of the basin was conceptualized prior to developing the Caloosahatchee Basin ISGM. Due to the complex hydrology of the basin, the model scale (1,500 ft) and the quantity of available field data, a simplified description was adopted. While attempting to maintain the major flow processes of the basin, the model was developed to simulate the fully dynamic flow and exchange comprising of the following:

- Ground water (4 layer geological model and two layer computational model)

- Unsaturated zone (5 characteristic soil columns)

- Evapotranspiration (10 characteristic vegetation cover classes)

- Overland flow (fully distributed controlled by overland water level and slope)

- Canals (primary irrigation and drainage canals including major hydraulic structures)

- Irrigation (irrigated areas and the conjunctive use of surface and ground water)

Calibration

As discussed in Conclusions section, the model was calibrated against surface water discharges and ground water heads in the upper and lower aquifer, respectively. The accuracy of the calibration was evaluated from the models ability to describe the average ground water heads and canal flows and secondly the dynamics.

The mean low flow of the C-43 Canal was simulated with a small absolute deviation while the relative error is high as the flow approaches zero. Peak flows are generally well described by the model.

The mean ground water potential heads of the shallow and deep aquifer were simulated by the model. The ground water dynamics is, however, underestimated for some of the deeper observation wells.

The model does not meet the calibration targets for the entire simulation period or for all calibration references.

Given the quantity of input data, the calibration is satisfactory. The model calibration accuracy must be evaluated against the uncertainty of input data and the complexity of the Caloosahatchee Basin hydrology. To obtain a closer agreement between observations and simulation further data must be provided.

Possible Model Improvements

In the development of the ISGM model the available field data were utilized. The developed model must be comprehensive to describe the dynamics and interactions of the basin hydrology. A number on general assumptions and approximations are necessary, in any model application, due to conceptualization, limitation in available input data, and distribution of model parameters.

When focusing on input data, the most critical shortcomings are found in the following areas:

River Flow and Water Levels

Data for cross-sections, floodplains, and hydraulic structures were sufficient to simulate the overall runoff and water levels in the basin. As the input data to a large extent is based on approximate data, an accurate description of canal hydraulics and flood extent is not possible. On the local scale, more data must be provided to obtain reliable flood mapping and detailed simulation of water levels and flows.

The Ground Water Model

The ground water model includes two numerical layers and four geological layers based on geological interpretation of previous model work. If additional lithological data are collected and reinterpreted, the geological model may be extended and refined. Although hydraulic parameters are not available for each layer a further subdivision is likely to improve the accuracy of simulated heads.

The ground water drainage component is important to the model results. It is desirable to provide a consistent method of transferring field data (e.g., density and depth of tertiary canal system to drainage depths and drainage time constants).

Irrigation Description

The irrigation description based on simulated water demands is seen as highly suitable for the Caloosahatchee Basin. Uncertainties are related to which areas should be considered irrigated, what are their primary and secondary sources, and if the distribution method applied is representative for all crops (e.g., sugarcane). Comparing different methods for calculating irrigation water demands and field measurements to the model results is important in determining if the adopted description should be refined.

Furthermore, crop specific evapotranspiration rates are desirable to reduce uncertainties in total evapotranspiration losses and generated irrigation demands.

Model Applicability

The Caloosahatchee Basin ISGM was developed to assist in water management of the Caloosahatchee Basin. The model was found to simulate the water use and the water budget with sufficient accuracy to be used for impact assessments focusing on future development incorporating management initiatives to improve the water resources situation in the basin.

The ISGM model incorporated both surface water and ground water and allows impact assessment of a wide range of management options (e.g., storage of surface water in reservoirs).

Considering the calibration accuracy it is advisable to minimize the uncertainty by interpreting the relative changes between a base case scenario and various alternative management scenarios.

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Appendix H
FRESHWATER INFLOW OF THE CALOOSAHATCHEE ESTUARY AND THE RESOURCE BASED METHOD FOR EVALUATION

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South Florida Water Management District

ABSTRACT

The Caloosahatchee River is the major source of fresh water for the Caloosahatchee Estuary and southern Charlotte Harbor aquatic environment. Development of an intricate system of canals within the basin, in conjunction with regulatory discharges from Lake Okeechobee, has resulted in a drastic alteration in freshwater inflow to this ecosystem. The resulting large fluctuations of salinity and water quality can adversely impact estuarine biota. This paper will describe: (1) important physical and hydrologic features of the Caloosahatchee Estuary and the potential environmental problems associated with extremes of high and low freshwater inflows; and (2) the South Florida Water Management District's (SFWMD) resource-based strategy for establishing an optimum distribution of freshwater inflows (quantity) in order to provide a suitable salinity range (envelope) for a healthy ecosystem.

SITE DESCRIPTION

The Caloosahatchee River bisects its basin and now functions as a primary canal (C-43) that conveys basin runoff and regulatory releases from Lake Okeechobee (**Figure H-1a**). The canal has undergone a number of alterations to facilitate increased freshwater discharge, including channelization, bank stabilization, and the addition of three lock and dam structures. The final downstream structure, Franklin Lock and Dam (S-79), demarcates the beginning of the estuary. This structure maintains two specified water levels upstream, discharges fresh water into the estuary, and acts as a barrier to salinity and tidal action, which historically extended upstream to the LaBelle area.

The Caloosahatchee Estuary and associated subbasin downstream of S-79 drains about 1,200 km^2 (**Figure H-1a**). The estuary length is approximately 42 kilometers (km) from S-79 to Shell Point. The City of Fort Myers is located about half way down the estuary on the south shore, whereas, the City of Cape Coral is on the north shore. Water leaving the Caloosahatchee Estuary passes Shell Point and enters San Carlos Bay, which is at the confluence of Pine Island Sound, Matlacha Pass to the north, and the Gulf of Mexico (**Figure H-1b**). Most of the fresh water that enters southern Charlotte Harbor comes into San Carlos Bay from the Caloosahatchee Estuary. Much of this fresh water normally leaves the system by moving south under the Sanibel Causeway to the Gulf of
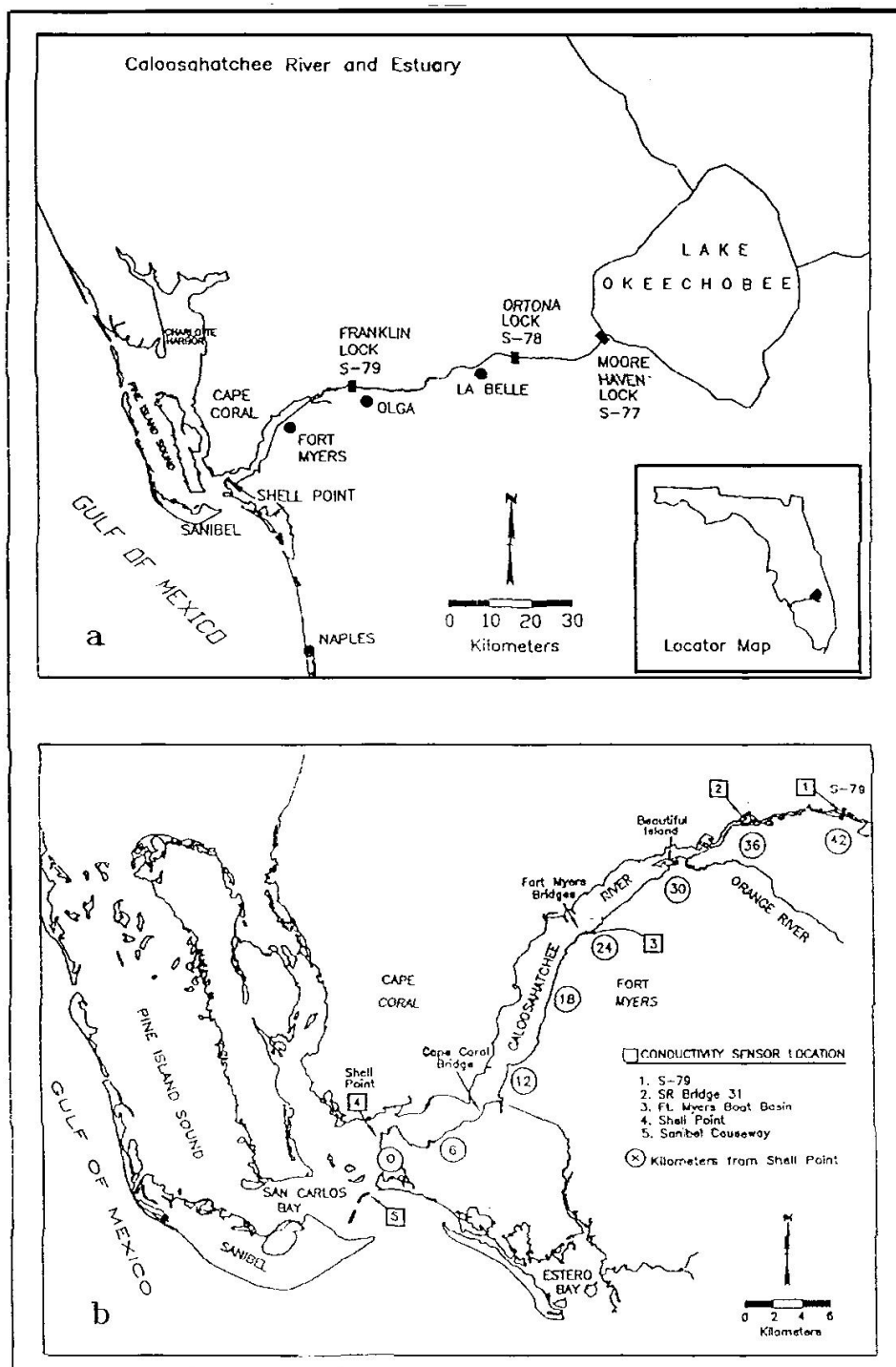
Figure H-1. a.) Caloosahatchee River and Estuary System; b.) Caloosahatchee Estuary and Location of Five Conductivity (Salinity) Sensors.

Mexico (Goodwin, 1996). However, when freshwater inflows are high, some of this fresh water is pushed by Gulf of Mexico tides up into Pine Island Sound and Matlacha Pass.

The estuary width between S-79 and Shell Point is irregular, ranging from 160 m in the channelized upper portion of the estuary to 2,500 meters (m) downstream (Scarlatos, 1988). The narrow portion extends about 12 km downstream from S-79 to Beautiful Island and has an average depth of about 6 m, while the overall mean depth of the estuary in the section downstream of Beautiful Island is 1.5 m (Scarlatos, 1988).

The Orange River enters the estuary just upstream of Beautiful Island (**Figure H-1b**). Although it is the only substantial tributary downstream of S-79, it contributes only a very small amount of the total fresh water entering the ecosystem (Scarlatos, 1988; Bierman, 1993). The Orange River is probably most famous for the large number of manatees in the winter that seek the warm water effluent from the Florida Power and Light Power Plant.

An important estuarine feature of this area is the submerged aquatic grass, *Vallisneria americana* (tape grass), which normally is located near the shoreline to a depth of 0.5-1 m. Its greatest coverage occurs from Beautiful Island to just past the Fort Myers bridges (**Figure H-1b**). However, this distribution varies as controlling environmental factors (such as salinity and light penetration) change with the amount of fresh water input (Chamberlain et al., 1996; Hoffacker, 1994). The presence of *V. americana* is associated with a greater density of benthic invertebrates and offers habitat, protection, and foraging sites for many fish and invertebrates, including juvenile blue crabs. Manatees also have been observed in the grass beds, indicating this area might be an important feeding location close to a warm water refuge. However, during times of extended low to no inflow conditions, when salinity may be too high, this grass becomes very sparse and can disappear completely.

At the downstream end of the system, sparse to moderately dense beds of the seagrass, *Halodule wrightii* (shoal grass), extend up from San Carlos Bay to nearly the Cape Coral Bridge (**Figure H-1b**). Like *V. americana*, it is restricted to the shoreline margins and represents a valued ecosystem component of the estuary.

The last substantial upriver oyster reef also exists near the mouth at Shell Point. Historical accounts of the river suggest that oysters were once a more prominent feature in this area. Sackett (1888) described difficulty surveying channels through oyster bars that obstructed the lower portion of the river between Redfish Point (river km 10) and Punta Rassa, where the Sanibel Causeway now connects to the mainland. The reduction in oyster coverage in this portion of the estuary was largely due to shell mining, altered freshwater inflow, and changes in hydrodynamics, which was probably exacerbated as the oyster bars were physically removed.

San Carlos Bay's dominant biological features are its numerous mangrove islands and many kilometers of mangrove shoreline, which are often closely associated with seagrass flats. Small oyster bars also are plentiful. These features provide a physical structure for a diverse population of aquatic organisms (Chamberlain et al., 1996), and

function as both a source of food and a place to feed and seek protection. Because of its biotic richness and aesthetic appeal, San Carlos Bay supports a wide variety of recreational and fishery activities with significant economic value, which must be considered along with agriculture and other upland interests when developing future water management policies.

When alterations to the natural system are made without adequate environmental consideration, the resulting physical and hydrologic changes in the estuary can have an adverse impact on the ecosystem and economy of the region. This was demonstrated by the previously described decline in oysters and again in the middle 1960s, when the S-79 Structure became operational, the Okeechobee Waterway was excavated through the estuary and the construction of the Sanibel Causeway was completed. These actions combined to convey more colored fresh water downstream and then restrict its natural exit to the Gulf of Mexico. Soon after the causeway was constructed, the previously flourishing bay scallop (*Argopectin irradians*) industry in this region collapsed, which the U.S. Fish and Wildlife Service (1960) predicted would occur due to lower salinity. Twenty years later, the Florida Department of Natural Resources (Harris et al., 1983) reported a significant decrease in seagrass cover in deeper areas, probably at least partially caused by a decrease in light penetration related to an increased amount of colored water.

Freshwater Inflow

When the magnitude of fresh water entering the estuary through S-79 from both the basin and Lake Okeechobee is evaluated for the period of record from 1966-1990, the greatest frequency of mean monthly inflows are in the 0-300 cubic feet per second (cfs) range (**Figure H-2**). The overall mean monthly inflow was in the 900-1,200 cfs range for this period of record. Since 1990, there has been an increase in the frequency of mean monthly flows in the high flow categories.

The long-term (1966-1994) mean daily discharge through S-79 (from the basin only, as well as from all sources combined) usually falls between 300 cfs and about 3,000 cfs, with lower discharge occurring during the dry season (**Figure H-3**). There also are high and low flow periods within each of the two seasons. This is largely related to the source of the water: Lake Okeechobee accounts for only about 25 percent, and rainfall runoff from the basin normally contributes the remaining 75 percent of the total discharge through S-79 during the wet season. If these percentages were constant throughout the year, then total daily discharge would be much lower in the dry season than depicted in **Figure H-3** (closer to the basin only trend). However, the actual percent contribution in the dry season of basin-only discharge is much less. This is due to the occasional regulatory discharges from Lake Okeechobee, which are most likely to occur during the dry season in order to lower the lake by the beginning of the hurricane (wet) season in June.

Daily and even monthly average inflow can be highly variable. To illustrate this point more clearly, **Figure H-4** compares daily wet season inflow in 1995 with the long-term average. If 300 and 2,800 cfs are used to bracket the normal daily wet season inflow
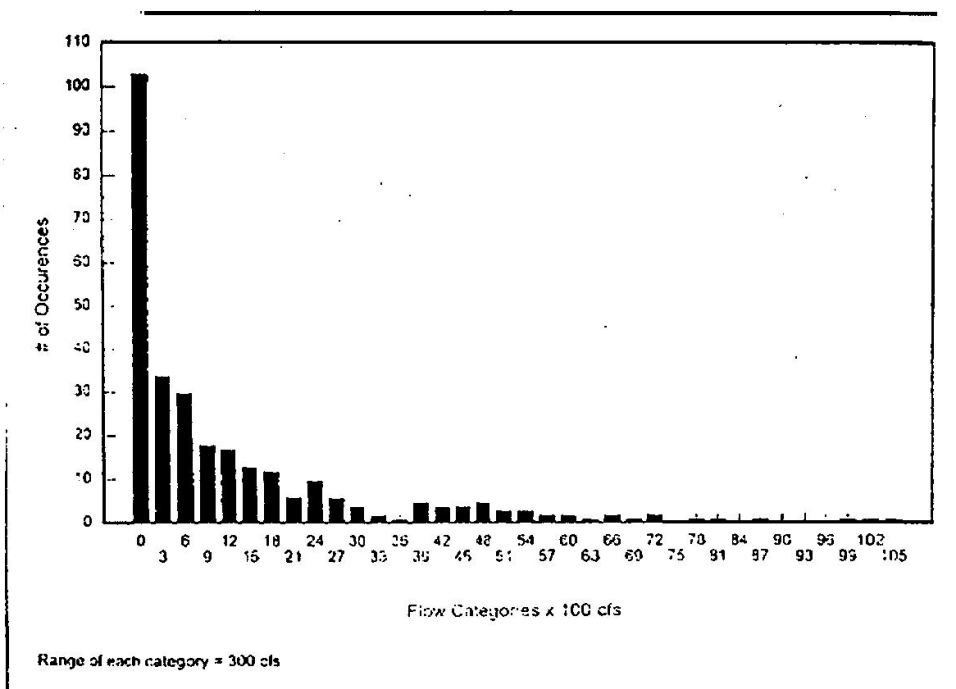
Figure H-2. Frequency of Mean Monthly Flow (cubic feet per second) from S-79 during the Period 1966-1990.
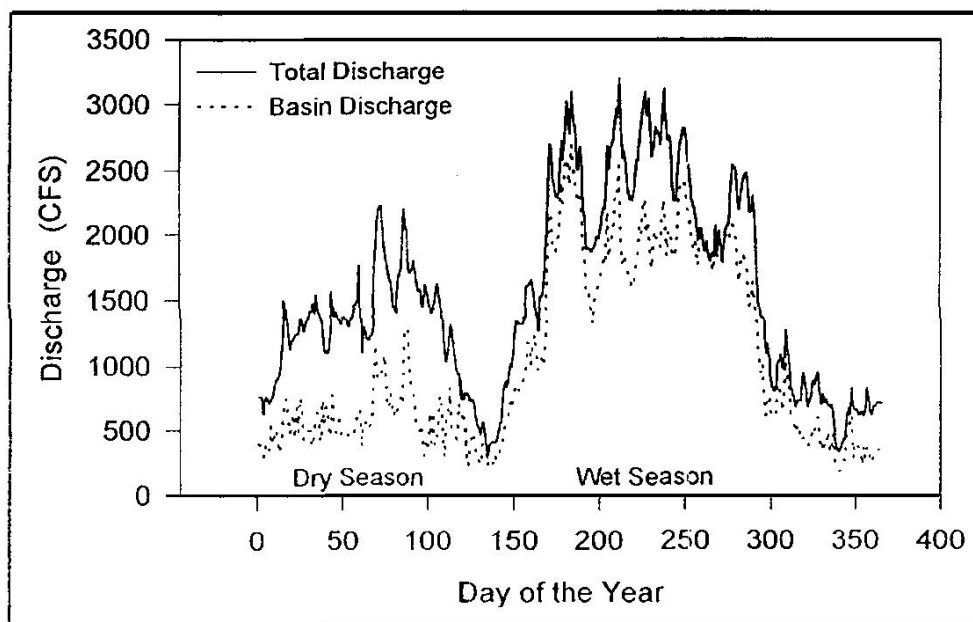
Figure H-3. Average Daily Freshwater Discharge (cubic feet per second) to the Caloosahatchee Estuary through S-79 during the Period 1966-1994 (n=29 for each day) Both Total (Lake Okeechobee plus basin) Discharge and Basin Discharge Depicted. Wet Season (day 121-304) and Dry Season (day 305-129) Indicated.

range, then flows in 1995 began below 300 cfs, bounced above 2,800 cfs several times, then remained well above normal (7,000- 17,000 cfs) during the later portion of the wet season. This was largely because of uncharacteristic wet season releases from the lake. Without the lake releases, S-79 daily discharges would have returned twice to the bracketed range and some measure of normal salinity could have returned to the lower estuary.
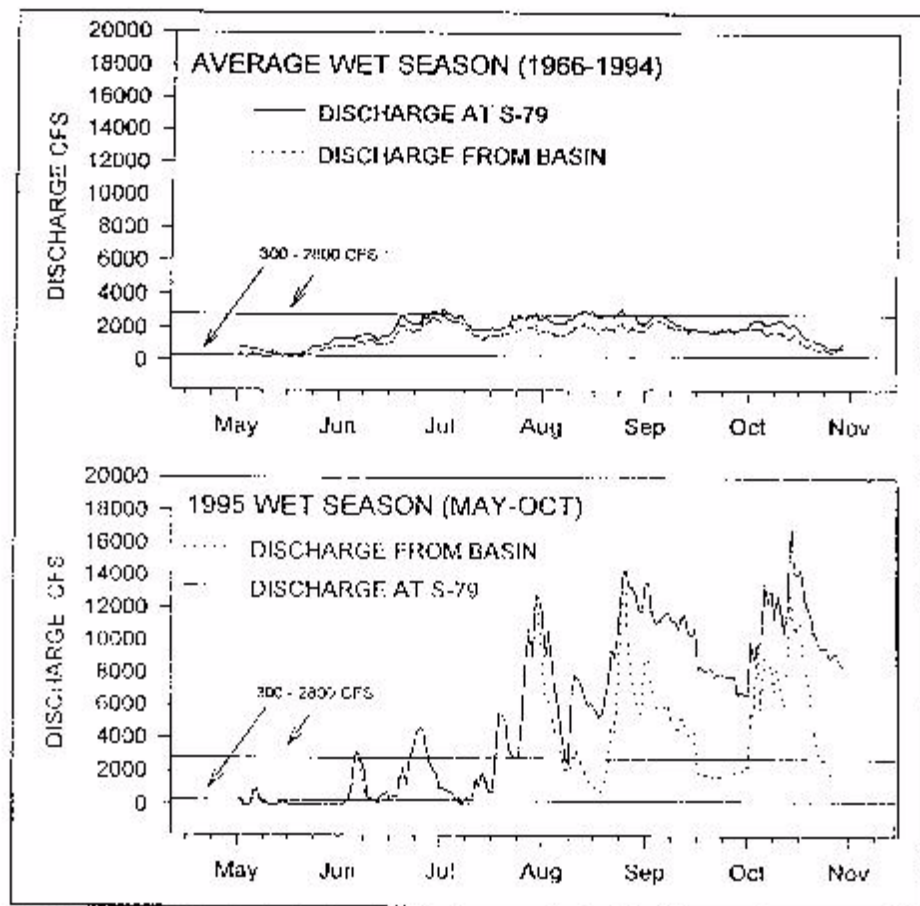
Figure H-4. a.) Average Daily Freshwater Discharge (cubic feet per second) to the Caloosahatchee Estuary through S-79 during the Wet Season (May- October) 1966- 1994 (n=29), and b.) 1995 only. Both Total (Discharge at S-79: Lake Okeechobee Plus the Basin) and the Basin Discharge Depicted.

Salinity

Many agencies, including SFWMD, have periodically sampled salinity in the estuary. The earliest records are prior to the completion of S-79 (Phillips and Springer, 1960; Gunter and Hall, 1962). Most of the historical collection efforts were for a short duration, usually at least a month apart and at different locations. In 1992, the District installed five continuous temperature and salinity sensors along the longitudinal axis of the estuary from S-79 to the Sanibel Causeway (**Figure H-1b**). These sensors collect data

every 15 minutes at 20 and 80 percent of the mean water depth, then store it until retrieval via cellular telephone. The continuous data allow water managers and researchers to view salinity throughout the system at any time and for any period of time. For example, **Figure H-5** displays the average daily salinity from those recorders for the 1995 wet season discussed earlier. As expected, the large inflow that year and high variability in discharge resulted in major changes in salinity. This can be best seen at Shell Point where salinity declined from full strength seawater (> 35 part per thousand [ppt]) to nearly freshwater conditions (< 5 ppt). Even farther downstream, Sanibel Causeway demonstrated a similar trend.

Ecosystem Research and Management

Discharge and salinity vary naturally in an estuary and exert a profound influence on the survival and distribution of estuarine organisms, especially early life stages (Pattilo et al., 1997). The importance of freshwater inflow to estuaries has been suggested to derive from the following:

1. The input of nutrients and organic matter for an adequate food supply

2. Protection from predation by more mature life stages that can't tolerate lower salinity or can't find prey in the naturally turbid estuarine waters

3. The range of salinity conditions available for a variety of organisms with different requirements for growth and development

4. The regulation of larval transport and retention

However, excessive variation in salinity can maintain estuarine biota in a constant flux between those favoring higher salinity and those favoring lower salinity (Bulger et al., 1990). At the extreme, appropriate salinity conditions do not last long enough for organisms to complete their life cycle and the estuary can become devoid of some self-sustaining populations and communities.

Proper management of water entering the estuary via the S-79 Structure is the predominant requirement for a healthy Caloosahatchee Estuary because the volume of fresh water passing through S-79 from the basin and Lake Okeechobee overwhelms any other source. Therefore, SFWMD initiated an ongoing research program in 1985 to (1) address impacts of basin and lake water management on the estuary; and (2) establish freshwater inflow limits and water quality targets for the estuary to guide future upriver activities.

The proper quantity will be defined by determining the optimum range of freshwater inflow that protects key biota. Key species, or valued ecosystem components, sustain ecological structure and function by providing food, living space, refuge, and foraging sites for other desirable species in the estuary. Oysters and submerged aquatic vegetation (SAV), such as the seagrass and tape grass described earlier, are considered key species in the Caloosahatchee Estuary research program. Therefore, it is assumed that
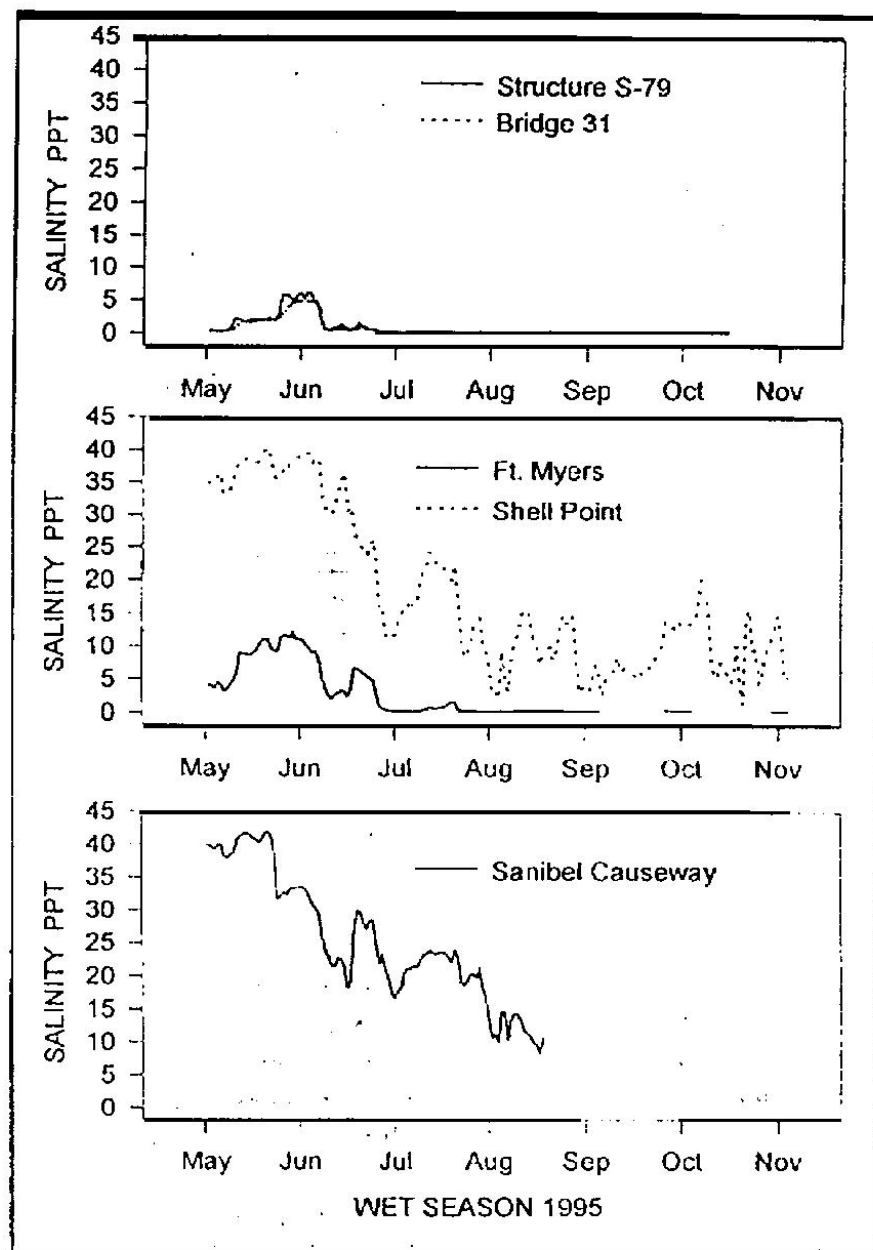
Figure H-5. Salinity in the Caloosahatchee Estuary during the 1995 Wet Season (Data Collected Using Continuous Conductivity Recorders).

limits of water quantity and quality that protect and enhance oyster and SAV productivity will lead to a healthy and diverse estuarine ecosystem. Bottom invertebrates, SAV, plankton (including larval fish and algae), and water quality have been sampled during various inflows and salinity conditions since 1986 to verify this assumption and to assess impacts of basin and lake water management. More recently, field and laboratory experiments are focusing on seagrass salinity tolerances to better understand their inflow limits. In the future, development of more sophisticated mathematical models will better predict salinity and water quality at locations along the estuarine gradient based on freshwater inflows. Thereafter, biota requirements for salinity, water quality, and habitat at key locations can be related to the inflows that match these requirements, based on model output, in order to determine the optimum inflow range. Finally, methods for assessing strategies and implementation success will be required. These methods will include biological monitoring, remote sensing techniques to detect change, and the acquisition of instantaneous (real time) information of environmental indicators such as salinity. This real time information will be necessary for water managers to understand the potential environmental impact to the estuary when they consider adjusting inflows to meet water supply and flood protection requirements. Development of real time management capability has already begun with the installation of the five continuous salinity sensors.

To date, a steady state computational model of salinity versus mean monthly flow has been developed by Bierman (1993). Mean monthly flow was determined as acceptable for initial evaluation because it adequately represents the approximate expected residence time for a variety of flow regimes observed in the system (**Figure H-6**). The results of Bierman's model (1993) along with historical salinity samples have been used to plot salinity versus distance down the estuary for a suite of selected mean monthly flow levels (**Figure H-7**). Model output indicates the entire range of salinity (0 to > 35 ppt) is represented when discharge is around 500 cfs. In essence, this discharge provides a desirable salinity somewhere for all organisms. A well represented range of salinity probably occurs up to about 1,000 cfs. However, when mean monthly discharges drop below about 250 cfs for extended periods of time, salinity climbs so high that it excludes the lower salinity ranges, which can adversely affect those plants and animals that exist in the upper estuary. During the other extreme, almost the entire estuary turns to fresh water when inflows exceed 4,500 cfs. Large mean monthly flows above 4,500 cfs can physically displace a large portion of the planktonic organisms and force pelagic species to seek their required conditions downstream in possibly a less desirable area. An extended period of depressed salinity throughout the system also can cause mortality of many bottom, nonmobile species. If this kind of perturbation is frequent, then establishment of a viable estuarine community of desirable species may be impossible in many portions of the system.

The salinity tolerance of several key estuarine organisms was determined from field surveys (Chamberlain et al., 1996) and literature values. Their area of distribution in the Caloosahatchee Estuary was then overlaid on top of the salinity vs. discharge graph (**Figure H-7**) to illustrate the District's resource-based management approach for estimating the proper freshwater inflow quantity (envelope). For example, if *V. americana* requires salinity < 10 ppt to remain dense enough to provide habitat for other organisms (Batiuk et al., 1992; Day, et al. 1989; Twilly and Barko, 1990; Chamberlain et al., 1996),
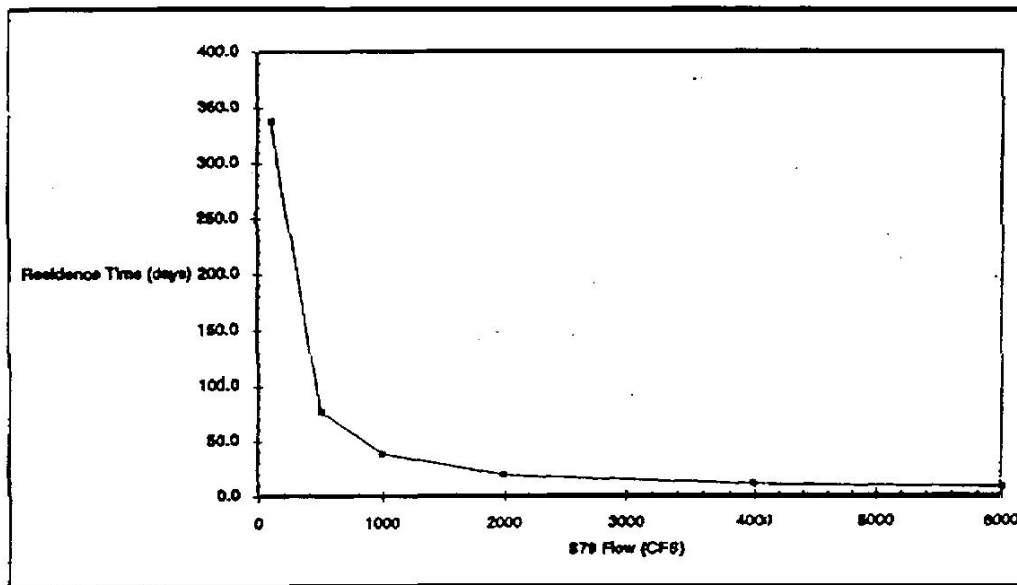
Adapted from Bierman, 1993

Figure H-6. The Amount of Time (days) Required to Move a Particle of Water from S-79 to Shell Point, due to Freshwater Flow from S-79 (Hydraulic Residence Time).
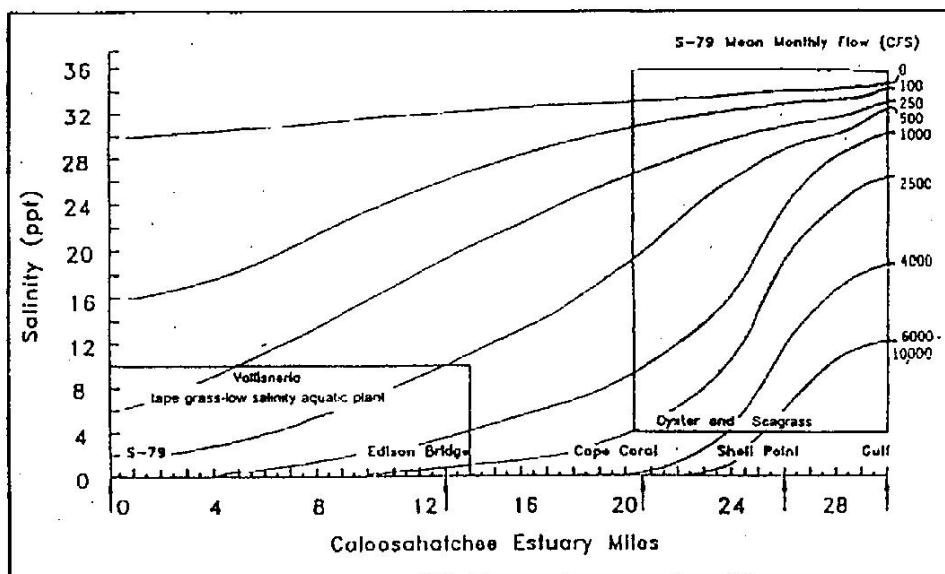
Figure H-7. Projected Longitudinal Salinity Distribution in the Caloosahatchee Estuary for Selected Mean Monthly Inflow Volumes from S-79 (Bierman, 1993). Literature reported tolerence limits for *Vallisneria americana*, *Halodule wrightii,* and Oysters Indicated with Estimated Current Spatial Distribution.

and if we desire to maintain it in this state down to Edison Bridge, then a minimum discharge of about 500 cfs will be needed. At the other end, if shoal grass and oysters can't tolerate salinity below about 4 ppt for an extended time (McMahan, 1968; Cake, 1983), and it is desired to continue having them viably distributed up to the Cape Coral Bridge area, then the maximum mean monthly discharge should not exceed about 2,500 cfs.

This represents a simplification of the approach, but serves to communicate the concept, which is the basis for the SFWMD research. The biological effects from freshwater input are felt directly (salinity) and indirectly (e.g. pulses of nutrients and organic material). To reduce uncertainty, the final target limits for the key species and other biota sampled will consider both types of impacts. Further analysis of monitoring efforts, and completion of experimental research, will lead to more sophisticated predictive models (SFWMD, 1995).

ACKNOWLEDGEMENTS

This manuscript was based on the general guidelines for estuarine research and management developed by Mote Marine Laboratory for the SFWMD. Application of their resource-based strategy to the Caloosahatchee was influenced by conversations with District staff, especially Dan Haunert, Al Steinman, and Nick Aumen. The actual field work and data analysis, which provided the necessary support information, depended on the efforts of many SFWMD staff, most notably Dan Crean and Kathy Haunert.

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Appendix I
PRELIMINARY ESTIMATE OF OPTIMUM FRESHWATER INFLOW TO THE CALOOSAHATCHEE ESTUARY: A RESOURCE-BASED APPROACH

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ABSTRACT

In the Caloosahatchee Estuary, establishing a suitable salinity environment is the most basic prerequisite for promoting estuarine biota in this system. The South Florida Water Management District (SFWMD) has adopted a resource-based research strategy with the intent of prescribing an acceptable freshwater discharge distribution within the salinity tolerance range of key estuarine species. To test this approach, submerged aquatic vegetation were selected as key species. This paper presents preliminary results and recommends a provisional inflow distribution.

INTRODUCTION

The Caloosahatchee River (C-43 Canal) and Estuary (**Figure I-1**) have been drastically altered to convey more basin runoff and regulatory releases from Lake Okeechobee. These changes have caused large fluctuations in freshwater inflow volume; frequency of inflow events; timing of discharges; and water quality in the downstream estuary. Therefore, the SFWMD initiated a long-term research program in 1985 to quantify the impacts of freshwater inflow from the Franklin Lock and Dam (Structure S-79) on downstream estuarine organisms. The resource-based management approach of this program seeks to define limits for freshwater inflow which provide a suitable salinity and water quality environment for key species. To test this research strategy, submerged vascular plants have been selected as key species.

One aspect of the estuarine research has been field monitoring of water quality and biota during a wide range of discharge events. The purpose of this paper is to report preliminary results of the relationship between freshwater inflow, salinity, submerged aquatic vegetation (SAV), and other estuarine species. These results are based on analysis of field monitoring efforts, in order to accomplish the following:

1. Establish provisional limits for the quantity of fresh water discharged to the estuary via S-79
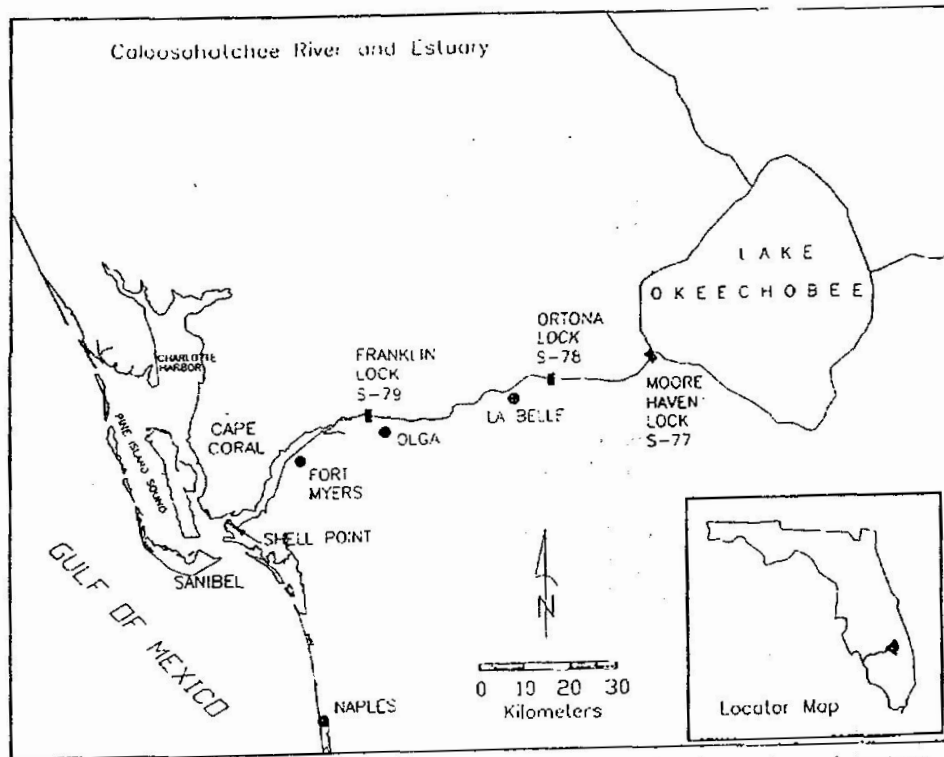
Figure I-1. Map of the Caloosahatchee River and Estuary, Showing Major Urban Centers and Structures.

2. Examine one of the major assumptions of the resource-based approach; that environmental conditions suitable for key species also will be suitable for other important biota

METHODS

A computational salinity model developed by Bierman (1993) for the Caloosahatchee Estuary was employed to mathematically define the influence of various freshwater inflows on salinity every 2 kilometers upstream from Shell Point to S-79. Modeling results compared freshwater inflow influence on the preferred salinity and distribution of SAV and other biota, which were determined from field sampling and the literature. The model also determined that salinity downstream to Shell Point is dependent (97 percent) on inflow from S-79 and that during average inflow conditions (~1,000 cubic feet per second [cfs]) the hydraulic residence time averages about one month. Therefore, for this report, freshwater discharge to the estuary is considered in terms of mean monthly inflow from S-79.

Field observations of *Vallisneria americana* by Hoffacker (1994), the authors of this paper, and others (Gunter and Hall, 1962; Phillips and Springer, 1960) served to establish a qualitative abundance index for comparison with salinity at the time of the

observation. Information from Hoffacker (1994) and the SFWMD were combined to produce a map of SAV distribution upstream of Shell Point (**Figure I-2**).
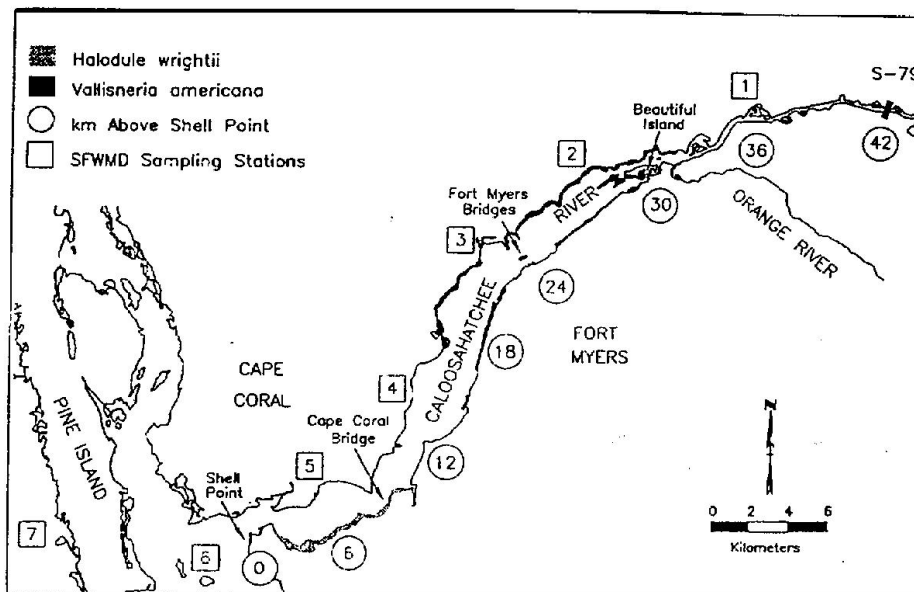
Figure I-2. Map of the Caloosahatchee River and Estuary Showing: Distribution of *Halodule wrightii* and *Vallisneria americana*; River Distances (in km) from the Mouth of the Estuary (circles); and Sampling Locations (1-7 squares).

Monthly water quality and biota sample collections occurred in three phases: phase 1 ran from 1986 into 1989 when S-79 inflows were usually low to moderate; phase 2 was conducted during 1994-1996 when discharges were often large; and two follow-up sampling trips (phase 3) to evaluate seagrass recovery were conducted in 1997. Sampling centered around seven locations in phase 1 (**Figure I-2**), areas 1 through 6 in phase 2, and only location 6 in 1997.

Repetitive random samples of the seagrasses, *Halodule wrightii* and *Thalassia testudinum,* were collected at locations 5 through 7 during phase 13 and area 6 in the remaining two phases. For this report, only the photosynthetic blades that were collected within 0.1 square meter (m) quadrat samples, then dried and weighed, were analyzed (dry weight biomass).

For this preliminary analysis, the effects of freshwater discharge on zooplankton, ichthyoplankton, and benthic macroinvertebrates were evaluated using the data obtained during phase 1 of the SFWMD field monitoring. All data that were not normally distributed were logarithmically transformed. The biota from each station were separated into flow categories (factor levels). A simple one-factor analysis of variance (ANOVA) was calculated to test for statistical difference between the mean monthly inflow categories ($p < 0.05$). A hierarchy evaluation (Scheffe multiple range test) for mean density between inflow categories was performed to determine which inflow levels were

associated with significantly more or less biota. Because adult finfish, crabs, and shrimp were not sampled, we relied on literature information from the Caloosahatchee Estuary and other Florida estuaries to estimate desired inflow conditions for these biota.

RESULTS AND DISCUSSION

Salinity and Freshwater Inflow

The salinity model results (Bierman, 1993) indicate that more than half the estuary upstream of Shell Point will become nearly fresh water and salinity will be reduced drastically downstream during even moderate mean monthly discharges of 2,000 cfs (**Figure I-3**). Inflows greater than 4,000 cfs will cause most of the estuary upstream of Shell Point to become fresh water and depress salinity (< 15 parts per thousand [ppt]) in portions of San Carlos Bay. At the other extreme, prolonged low to no flow (< 100 cfs) results in salinity condition near S-79 that exceed 15 ppt: eliminating any tidal fresh water or oligohaline zone within the estuary.
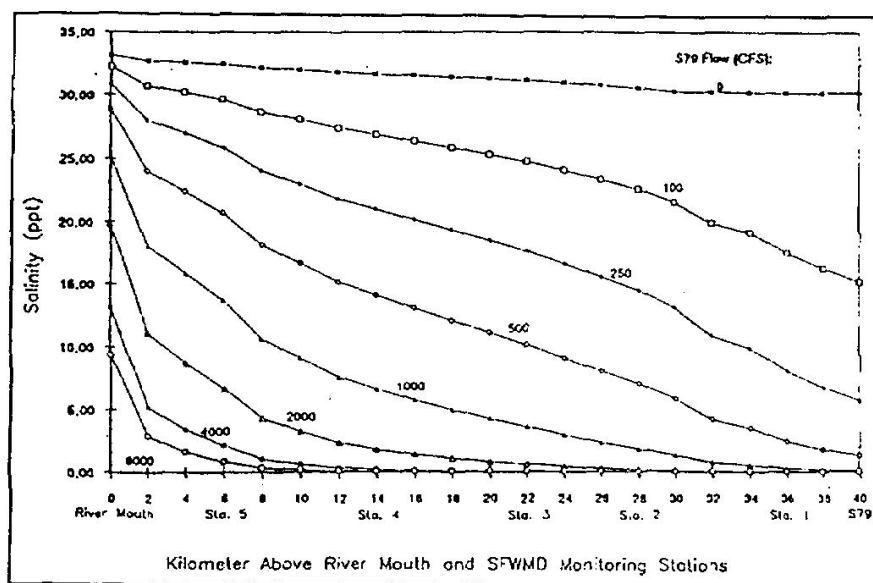
Figure I-3. Projected Steady-State Longitudinal Salinity Distribution in the Caloosahatchee Estuary for a Range of Freshwater Inflows (Bierman, 1993). The X-axis Corresponds to Distance from Shell Point (km).

V. americana longitudinal distribution is about 18 km during ideal growing conditions and stretches from its upstream limit at 32 kilometers (km), as measured from Shell Point, to its downstream limit at 14 km (**Figure I-2**). Based on this distribution, we estimated that over 80 percent of the total area covered by moderate to dense stands of *V. americana* under favorable growing conditions are in the first 4 km (28 through 32) of its upstream limit.

Literature information indicates that *V. americana* growth steadily declines with increasing salinity until it ceases at approximately eight to nine parts per trillion (ppt), but it can tolerate salinity (survive) up to 11 to 13 ppt (Day et al., 1989; Twilley and Barko, 1990). The qualitative information assembled from observations in the Caloosahatchee Estuary (**Figure I-4**) is consistent with these limits and indicates that density declines where salinity is above 10 ppt. A similar plot of biomass versus temperature reveals no trend, suggesting little influence of temperature on *V. americana* distribution in this system.
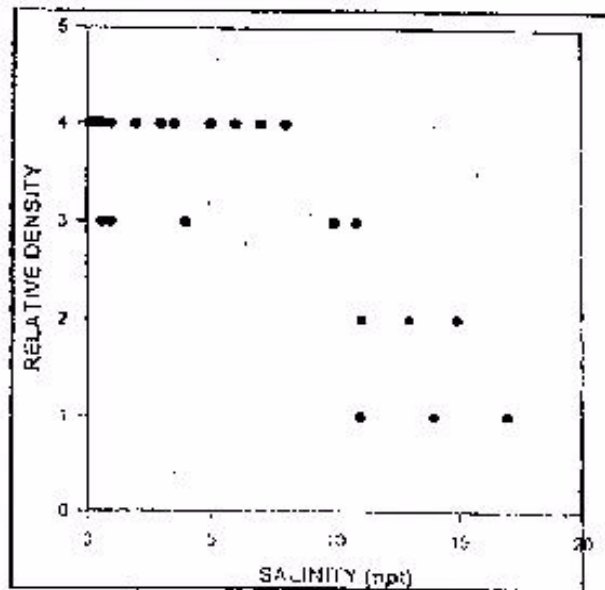
Figure I-4. Relative Density of *Vallisneria americana* as a Function of Salinity in the Caloosahatchee Estuary. Density Ranks Equate to the Following: 1 = absent; 2 = absent to sparse; 3 = moderately dense; and 4 = dense. Each Circle Corresponds to One Obsevation (Phillips and Springer, 1960; Gunter and Hall, 1962; Hoffacker, 1994; and SFWMD).

Employing the results of the model by Bierman (1993, Figure 3), it appears that at least a 300 cfs mean monthly discharge from S-79 is required to maintain *V. americana* in the system. Analysis of historical S-79 discharges determined that attaining the 300 cfs minimum inflow will be a concern only during the November through May dry season. Therefore augmentation of flow should be considered during this time. Discharges that approach 400 through 500 cfs will provide salinity conditions of less than 10 ppt within the portion of the estuary that support most of the total *V. americana* coverage. To provide salinity conducive for *V. americana* throughout its entire 18-km range will require mean monthly discharges of approximately 800 cfs.

H. wrightii is the only seagrass species consistently found around station 5, upstream of Shell Point, until it mixes downstream with *T. testudinum* in San Carlos Bay

(**Figure I-5**). *H. wrightii* has a much smaller distribution upstream of Shell Point than *V. americana.* It ranges only from 2 to 10 km upstream of Shell Point, with the greatest coverage per two km segment within the 4 to 6 km area. *H. wrightii* is reported to have a wide salinity tolerance by McMahan (1968). It does not survive below 3.5 ppt and prefers salinity as high as 44 ppt. This wide tolerance is probably why it is the only true seagrass species encountered inside the Caloosahatchee Estuary at station 5, although high discharges probably limit its productivity. The lowest biomass occurs inside the estuary where salinity is also lowest and most variable. Graphically and statistically, biomass of *H. wrightii* is greater when salinity is above 20 ppt (**Figure I-6**). Statistically, the greatest biomass occurs when salinity is greater than 28 ppt.
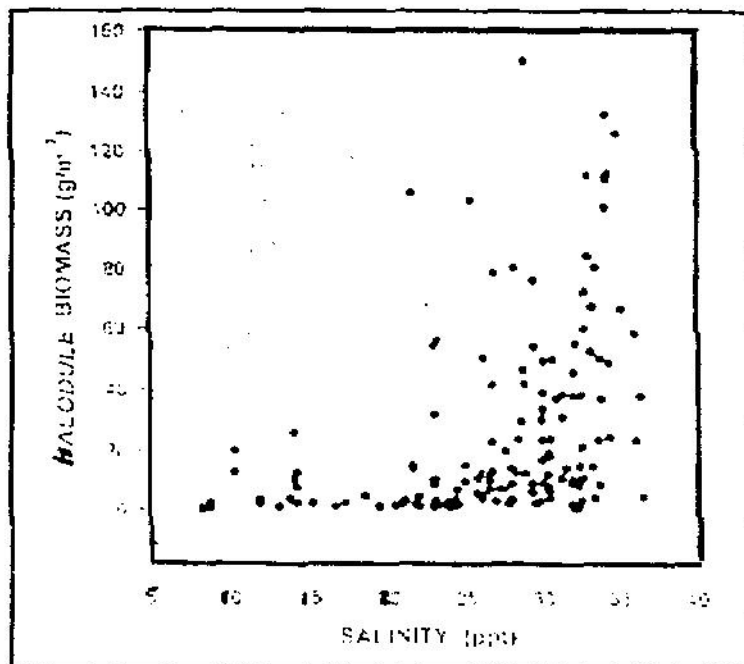
Figure I-6. Mean Biomass of *Halodule wrightii* (dry weight) and Salinity per Sampling Trip at Each Sampling Station for All Seasons Combined.

Literature summarized by Zieman and Zieman (1989) indicates that the optimum salinity range for *T. testudinum* is 24 to 35 ppt, with maximum photosynthetic activity occurring at 35 ppt and decreasing linearly with declining salinity. *T. testudinum* does not normally grow in areas where salinity is below 17 ppt. These literature values are consistent with preliminary monitoring results for the Caloosahatchee Estuary (**Figure I-5**). *T. testudinum* does not exist inside the estuary (in Iona Cove: area 5), where salinity during sampling was more variable, with a standard deviation that extended below 20 ppt due to long periods below 10 ppt. Like *H. wrightii*, the biomass of *T. testudinum* is statistically greater when salinity is above 20 ppt, regardless of season.

According to the Bierman model and statistical analysis, the 400 to 500 cfs needed to support over 80 percent of the *V. americana* will not lower salinity below that preferred by *H. wrightii* (> 20 ppt) anywhere in its current range. Salinity begins to approach the reported mortality limit of *H. wrightii* (3.5 ppt) in area 5 when average discharges
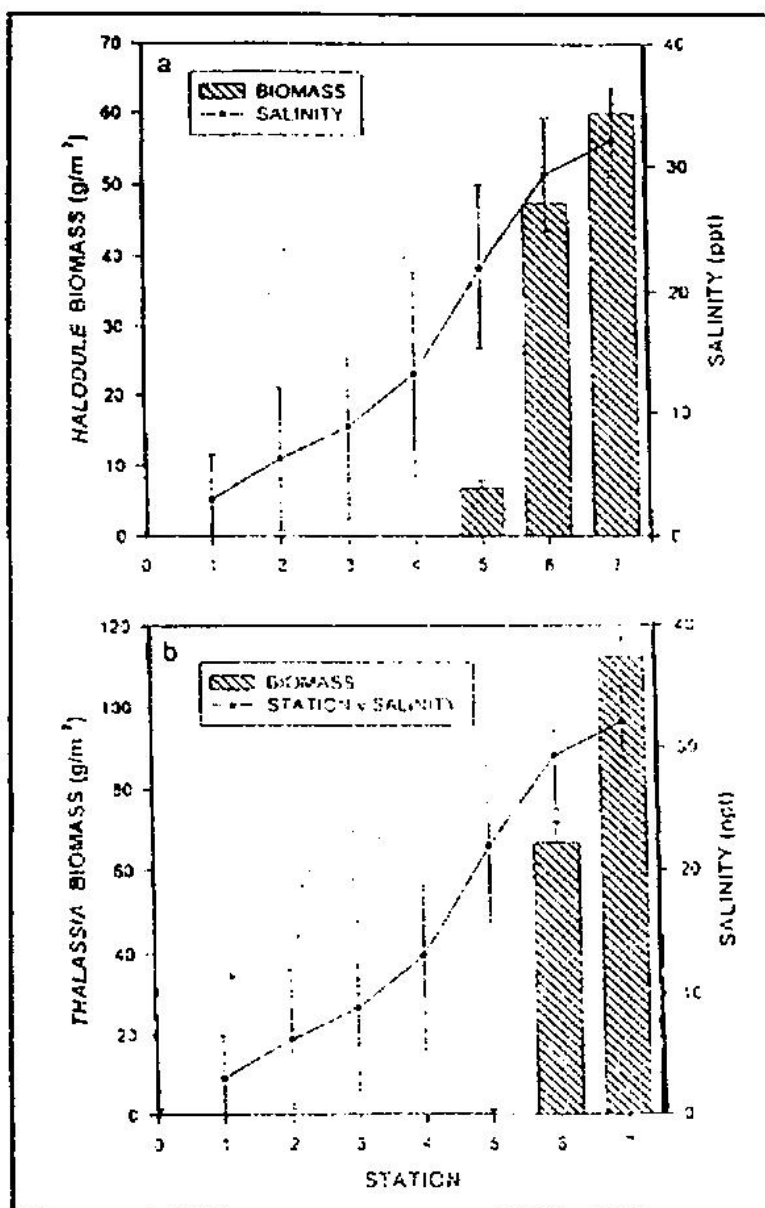
Figure I-5. a.) Mean Biomass (+ 1 Standard Deviation) of *Halodule wrightii* (dry weight) and Salinity (+ 1 Standard Deviation) at Each Sampling Station for All Seasons Combined, and b.) Mean Biomass (+ 1 Standard Deviation) of *Thalassia testudinum* (dry weight).

approach 3,000 cfs for more than a month. Both *H. wrightii* and *T. testudinum* biomass are statistically greatest throughout their respective distributions when mean monthly inflow is less than about 800 cfs for more than two months. In San Carlos Bay, mean monthly inflows greater than 4,500 cfs for two or more months are statistically associated with the least biomass for both species.

Finfish

At least 75 percent of Florida's recreational fishes depend on estuaries for at least a portion of their life. The most important role of estuarine systems is as a nursery area for juvenile stages (Seaman, 1988). In the upper Caloosahatchee Estuary, Gunter and Hall (1962) reported the greatest catches in seines consisted of juveniles, during midwinter inflow that reduced salinity in the inner estuary to 1 to 5 ppt (station area). Seine catches in the outside water (San Carlos Bay area) were greatest when salinity was high, therefore, establishment of a minimum inflow for *V. americana* should generally benefit the finfish of the estuary by providing a salinity gradient that includes desired low salinity conditions upstream for juveniles. Maintenance of this minimum flow is apparently most critical during the winter dry season. However, year round high maximum inflow limits that maintain salinity downstream of Shell Point also appear beneficial.

Bay anchovy (*Anchoa mitchilli*) juveniles and adults were the third most abundant fish collected by Gunter and Hall (1962), with 94 percent of the fish caught upstream of Shell Point. Most of the juveniles they caught were from near zero salinity water at stations close to *V. americana* beds at Beautiful Island and the Fort Myers bridges. This is consistent with Jones et al. (1978), who reported that juveniles often ascend rivers above brackish waters, therefore, inflows within the optimum range for SAV (300 - 800 cfs) should not adversely impact bay anchovies and should provide better conditions for their development and food production.

Redfish (*Sciaenops ocellata*) are an important game fish in Florida. Spawning occurs seaward of estuary passes during late summer and fall. Seaman (1988) reported that seagrass meadows are primary habitat for young redfish. Once in the estuary, juveniles feed on benthic organisms from October to February and later on small fish and shrimp. Collections of redfish in the Caloosahatchee Estuary (Phillips and Springer, 1960; Gunter and Hall, 1962) were almost exclusively inside the estuary with salinity ranging from 0.2 to 14 ppt, therefore, promoting dry season inflows conducive for SAV also will provide salinity and habitat for redfish recruitment and development.

Ichthyoplankton

Anchoa spp. comprised 76 percent of the SFWMD ichthyoplankton samples during 1986 - 1989 (unpublished data). The greatest density occurred during April through July, followed by the period of December through March. During the dry season, when inflows will need to be augmented for *V. americana*, high inflows greater than 2,500 cfs were associated with the lowest mean ichthyoplankton density, regardless of location in the estuary. Mean density within the flow category of 300 to 600 cfs were at least the

second highest at all stations, and therefore represented the optimum overall flow category.

The presence of developing fish eggs provides a good indication of the spawning location and recruitment success of fish in an estuary. Statistical analysis of eggs within ichthyoplankton samples during the dry season found significant differences existed among inflow categories: inflows in the range of 150 to 600 cfs were associated with the highest mean egg density at stations 1 through 4; and density decreased as inflows increased above this category. In fact, no eggs were ever collected during this season at stations 1 through 5 when inflows were greater than 2,500 cfs and substantially fewer eggs were collected at station 6. Reduced egg density during high inflows are assumed to be related to a 'flush-out' effect, so similar impacts probably exist during the wet season.

Zooplankton

Zooplankton provide a crucial link in the estuarine food web when they consume free floating microscopic plants (phytoplankton) and transfer plant energy to higher trophic levels. Dominant forage fishes such as bay anchovy, as well as juvenile stages of most estuarine fish species, depend on zooplankton as a food source.

Within each season, mean zooplankton density increased with increasing salinity and distance from S-79. In general, zooplankton density was greatest during April through July. Collections during this time period appeared sensitive to high flows. Inflows greater than 1,500 cfs resulted in the lowest mean density at all stations. Evaluation of dry season inflow (November - May) revealed significant lower density with flows greater than 1,200 cfs. Zooplankton mean density associated with inflows between 300 to 600 cfs were consistently among the greatest encountered at each station.

Invertebrates

In the Little Manatee River (Southwest Florida), Peebles and Flannery (1992) reported that transfer of the estuary food source to juvenile fish appeared to occur largely through their feeding on benthic organic material, therefore, the density of benthic organisms can strongly influence the survival of many higher trophic species. The SFWMD benthic macroinvertebrate survey (unpublished data) found that the Caloosahatchee Estuary supports a large number of species (519). The majority of these are sessile and cannot relocate to a more favorable location when water quality deteriorates. Caloosahatchee Estuary inflows within the optimum range for *V. americana* appear conducive for supporting a wide range of benthic infauna. Statistical analysis of dry season data indicate that peak benthic macroinvertebrate density at stations 1 through 4 was associated with inflows (150 - 600 cfs) that establish salinity in approximately the mesohaline range (5 - 18 ppt). This same preliminary analysis also indicated that mean monthly discharges greater than 3,000 cfs are associated with the lowest densities at stations 1 through 4.

Penaeid shrimp probably represent the most economically important fishery in Florida (Seaman, 1988). Mating and spawning occurs offshore and the postlarvae migrate

into the estuary and seek shallow areas with vegetation and/or abundance of organic detritus. The loss of SAV directly reduces fishery yields (Seaman, 1988). Gunter and Hall (1962) indicated pink shrimp (*Penaeus duorarum*) were common in seine and net samples in the Caloosahatchee Estuary. Haunert (1987) reported pink shrimp abundance increased after inflows increased in the St. Lucie Estuary, but decreased when inflows caused salinity to decline to oligohaline conditions (< 5 ppt), which are not tolerated well by pink shrimp (McFarland and Lee, 1963; Gunter et al., 1964). Therefore, in the Caloosahatchee Estuary, minimum and maximum inflows that promote SAV at both the inner estuary and the Iona Cove-San Carlos Bay regions should provide ideal salinity for pink shrimp and support bottom vegetation habitat important for postlarvae development.

The Caloosahatchee Estuary supports a year-round commercial and sport fishery for blue crabs (*Callinectes sapidus*). This species also is an important source of food for many fish. The first development stages are planktonic, which prefer 30 ppt and will perish if exposed to salinity less than 20 ppt (Millikin and Williams, 1984). After settling out of the plankton, each subsequent juvenile phase of both sexes is concentrated in progressively lower salinity because of their continuing migration up the estuary (Millikin and Williams, 1984). Juvenile and adult blue crabs also occur in much higher densities in areas covered by vegetation. Therefore, inflows in the range of 300 to 800 cfs will be beneficial for blue crabs because of their salinity requirement throughout the Caloosahatchee Estuary, as well as the SAV habitat that these flows promote in both the inner and outer estuary.

Estimate of Optimum Inflow

Table I-1 recommends provisional inflow ranges and timing for maintaining the health of the important taxa discussed above and others. The preliminary analysis suggests that a minimum inflow of 300 cfs for *V. americana* during the dry season will not be harmful, but inflows greater than about 2,500 to 3,000 cfs may be detrimental to other biota anytime of the year. Therefore, a distribution of inflows that has the greatest frequency range from 300 to less than 1,500 cfs, with a peak of 300 to 800 cfs, should be generally beneficial to all the biota evaluated.

Beyond identifying the optimal timing and distribution of inflow, we also must consider that freshwater inflow varies naturally as a function of rainfall. Inclusion of this natural variation is important to insure a diverse composition of estuarine biota. Ultimately, this will mean a defined percent of violations should be allowed for both the high and low discharge limits. As a first attempt to define this environmentally sensitive distribution of S-79 discharges, an optimization program (computer model) was employed (Labadie, 1995; Otero et al., 1995). The program utilized historic watershed runoff data for the 1966 - 1990 period (without Lake Okeechobee releases). The desired inflow ranges (limits for the biota) are input variables to the model, along with the natural periodicity of violations of the upper and lower limits (estimated from the 1966 - 1990 historic data). For the Caloosahatchee Estuary, 20.5 percent violation of the lower limit and 5.5 percent violations of the upper limit created inflows that emulated the natural variability established from rainfall during 1966 to 1990. In addition to natural variation, the resulting frequency distribution generated by the model (**Table I-2**) reveals that the

Table I-1. Provisional Recommended Inflows (cfs) for Promoting the Health of Selected Taxa in the Caloosahatchee Estuary.

Species	Lower Inflow Limit (LIL)	Preferred Inflow Range (PIR)	Upper Inflow Limit (UIL)	Important Months
Vallisneria	300	> 400	---	Dry Season (Nov.-May) - LIL, PIR
Halodule Thalassis	---	< 800	3,000 for *Halodule* 4,500 for *Thalassis*	All Year - UIL
Fish (general)	300	300 - 1,300	3,000	Dry Season- PIR All Year - UIL
Bay Anchovy	300	300 - 800	3,000	Dry Season - PIR All Year (esp. Spring) - UIL
Silver Perch	300	300 - 800	3,000	Dry Season - PIR All Year (Esp. Jan. - Early Summer) - UIL
Redfish	300	300 - 800	3,000	Dry Season (Esp. Nov. - Mar.) - PIR All Year (Esp. July - Dec.)
Snook	300	300 - 1,500	3,000	Late Dry Season - PIR All Year (Esp. Late Dry Season) - UIL
Larval Fish	---	300 - 600	2,500	Dry Season (Esp. Spring - Early Summer)
Fish Eggs	---	150 - 600	2,500	All Year
Pink Shrimp	300	300 - 800	3,000	All Year
Blue Crabs	300	300 - 800	3,000	All Year (Esp. Feb. - July)
Zooplankton	---	300 - 600, < 1,500	2,500	All Year
Shrimp and Crab Larvae	---	< 1,300	2,500	All Year (Esp. Spring- July)
Benthic Macroinvertebrates	---	300 - 800	3,000	All Year
Oysters	---	300 - 800	3,000	All Year

appropriate inflow limits were attained (300 - 2,800 cfs) and the greatest frequency of inflows were within the range from 300 to 1,300 cfs, with peak of inflows between 300 to 800 cfs.

The above recommended optimum flow distribution is provisional, based on the data currently evaluated, preliminary model results, and our best professional judgement. A final distribution will be established after a better understanding of the salinity tolerances of seagrass and other species is determined. This will be accomplished by conducting a more detailed evaluation of the field data than provided in this summary and completing field and lab experiments, which have already begun.

Table I-2. Proposed Frequency Distribution of Freshwater Inflows to the Caloosahatchee Estuary for 1966 to 1990, Generated by the Optimization Model.

Frequency of Occurrence (percent)	Discharge Range (from S-79) cfs
20.5	0-300
44.2	301-800
15.7	801-1,300
5.5	1,301-1,800
4.8	1,801-2,300
3.9	2,301-2,800
5.5	> 2,800

ACKNOWLEDGEMENTS

The resource-based strategy was based on peer reviewed guidelines developed by Mote Marine Laboratory for SFWMD estuarine research, and applied in the St. Lucie Estuary. Mote Marine Laboratory also identified and enumerated the organisms contained in the Caloosahatchee Estuary samples. The field work, sample processing, and data management depended on the effort of many SFWMD staff, most notably Dan Crean and Kathy Haunert.

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Appendix J
ANALYSIS OF WATER AND NUTRIENT BUDGETS FOR THE CALOOSAHATCHEE BASIN DEVELOPMENT OF IRRIGATION AND DRAINAGE NETWORKS FOR THE CALOOSAHATCHEE BASIN

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SUMMARY

Irrigation and drainage information is an important component for evaluating the water resources of the Caloosahatchee Basin. In this basin, approximately 65 percent of the land may be irrigated each year and 40 percent of the land may receive water from Lake Okeechobee. Nearly 90 percent of the basin has been affected by man-made drainage. In this task, the irrigation and drainage patterns were evaluated and the irrigation network and drainage network were developed that include the pumps and structures that control water flow.

The drainage network was developed based on the USGS hydrography which describes many of the drainage paths for storm water runoff. However, the hydrography coverage was incomplete and soils, topography, and road coverages were used with aerial photographs to identify additional drainage paths. The drainage network provides a continuous flowpath from source areas of overland flow to the Caloosahatchee River. The outfall water control structures for each South Florida Water Management District (SFWMD) surface water permit and major urban structure were included with the drainage network. The historical drainage paths were developed from 1932 U.S. War Department maps. A comparison with the historical drainage indicates that there have been substantial changes in the drainage patterns in the basin.

In the future, it is likely that more surface water storage facilities will be required to provide supplemental irrigation water. Impoundments have been build as part of many surface water permits to protect local wetlands or detain runoff water to prevent downstream flooding. These impoundments have been identified from surface water permits, water use permits, and aerial photography. There are approximately 14,000 acres of impoundments in the basin. Most of the impoundments are near the basin boundaries and few are near the river. These impoundments would not provide useful storage for river water or tributary runoff.

The irrigation network was developed by identifying the parcels that irrigate using water from the Caloosahatchee River. The irrigated land is in the Lake Okeechobee

Service Area (LOSA), which is land that can receive supplemental irrigation water from Lake Okeechobee. Approximately 45 percent of the 340,000 acres of irrigated land in the basin receives irrigation water from the river. There are over 2,000 irrigation pumps in the basin, of which 245 pump water from the river. The remaining pumps use ground water or local surface water. The canal system that provides water to the irrigated land in the LOSA was developed into the irrigation network. There are several large diversion pumps that maintain the water levels in several primary irrigation canals. The farm pumps obtain the necessary irrigation water from these canals.

INTRODUCTION

The Caloosahatchee Estuary, an important habitat and recreational resource in Southwest Florida, has been degraded by excessive freshwater discharge and poor inflow water quality. Excessive discharge disrupts the salinity of the estuary, which harms the seagrass habitat of some juvenile fish. Excessive freshwater discharge originates from flood control releases from Lake Okeechobee via the Caloosahatchee Canal (C-43), as well as storm water runoff from the basin. The high discharge may occur during the dry season when the water is typically released from the lake to reduce lake stage prior to hurricane season. Typically, storm water runoff is high during summer wet season when the ground water is near land surface and the growers need to rapidly drain the farmland. The runoff from the basin has been altered by both agricultural and urban development often resulting in increased volume and higher peak runoff.

While excessive freshwater discharge harms the estuary, there is a need for freshwater for urban and agricultural water users in the basin. Water supply and runoff volume and timing are critical issues in the Caloosahatchee Basin. Water from the Caloosahatchee River is necessary for supplemental irrigation, urban consumptive use, and the estuary habitats. In the past, adequate water was available from Lake Okeechobee to meet these supplemental and consumptive water use needs. However, with increasing demand on Lake Okeechobee from other users, such as the Everglades and the urban users on the lower east coast, the volume of water available for the Caloosahatchee Basin will be reduced. To meet the needs of the Caloosahatchee Basin, it will be necessary to develop a better understanding of the water resources of the Caloosahatchee Basin and develop the means to efficiently conserve and utilize the available surface water.

An important step in evaluating the water resources is to develop an inventory of the surface water features and facilities in the basin. This inventory is necessary to input data for hydrologic models simulating behavior of the system. The drainage system includes the drainage flowpath network and facilities that control drainage. The facilities include discharge structures for agricultural operations and drainage control structures for urban land. The water use features and facilities include the network of irrigation canals and the surface water irrigation pumps in the Caloosahatchee Basin. In particular, it is important to locate and characterize pumps within the LOSA (**Figure J-1**).

Drainage networks were developed for the tributary basins of the Caloosahatchee Basin to provide a network of flowpaths to support hydrologic modeling and subbasin
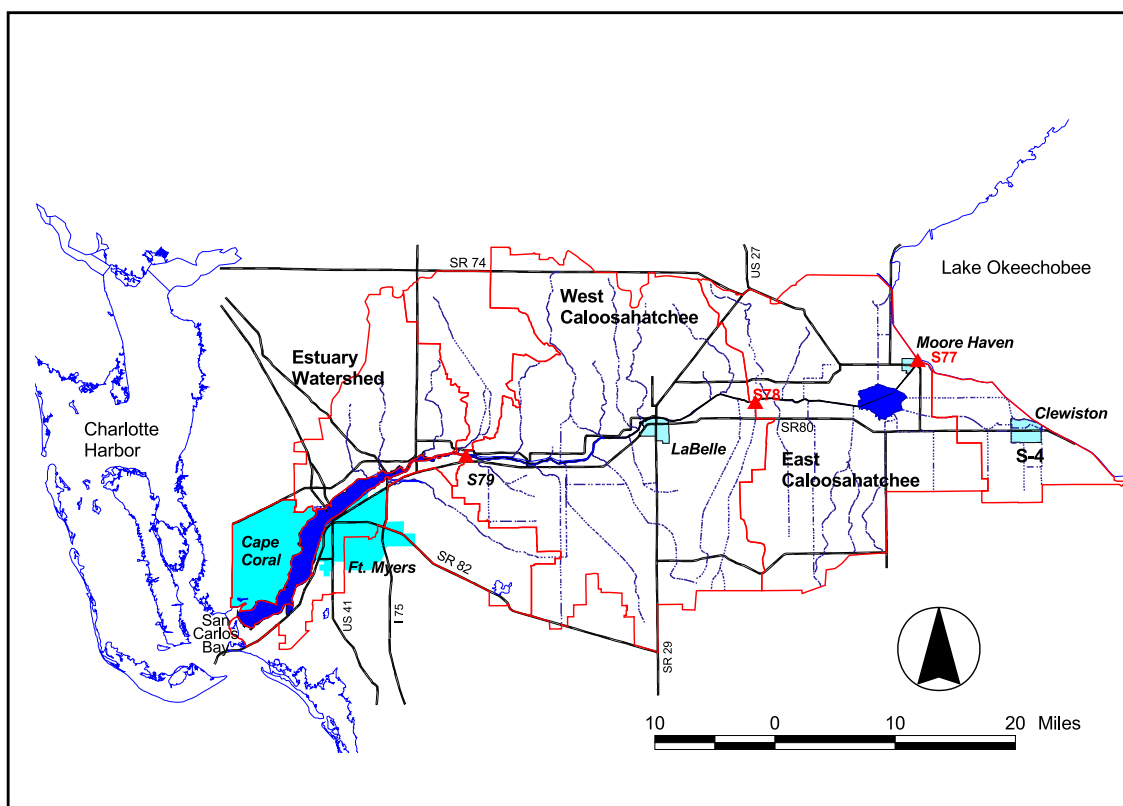
Figure J-1. Primary Drainage Basins and Discharge Structures in the Caloosahatchee Basin.

boundary identification. Development of the subbasin boundaries was described in the Task 5 report (Flaig et al., 1998a) and will not be discussed in this report. The Caloosahatchee Basin was divided into 104 subbasins based on the drainage network (**Figure J-2**). Historically, there were approximately 20 tributaries to the Caloosahatchee River and Estuary, however, construction of drainage ditches and canals has increased the total number of tributaries. There are over 150 discharge sites along the river and estuary.

The basin was divided up into 104 subbasins that each drained a substantial area and had one major discharge point. Most of the subbasins drain directly to the river or estuary. A few subbasins have major control structures along the primary drainage path and were split into upstream and downstream subbasins.

This report presents the irrigation and drainage networks for the Caloosahatchee Basin. The irrigation network was developed that describes the flowpaths for irrigation water from Lake Okeechobee through the Caloosahatchee River to agricultural fields. The network connects the surface water irrigation pumps to the C-43 Canal. The drainage network was developed from the hydrography coverage and modified using the wetlands, soils, and land use coverages to identify additional flowpaths. The network includes the primary drainage paths; in densely drained areas only the farm canals are included while in the less developed areas small field ditches were included to paths of concentrated flow. For comparison, the predevelopment drainage hydrography was extracted from old U.S. War Department topographic maps and converted into an Arc/Info coverage. This
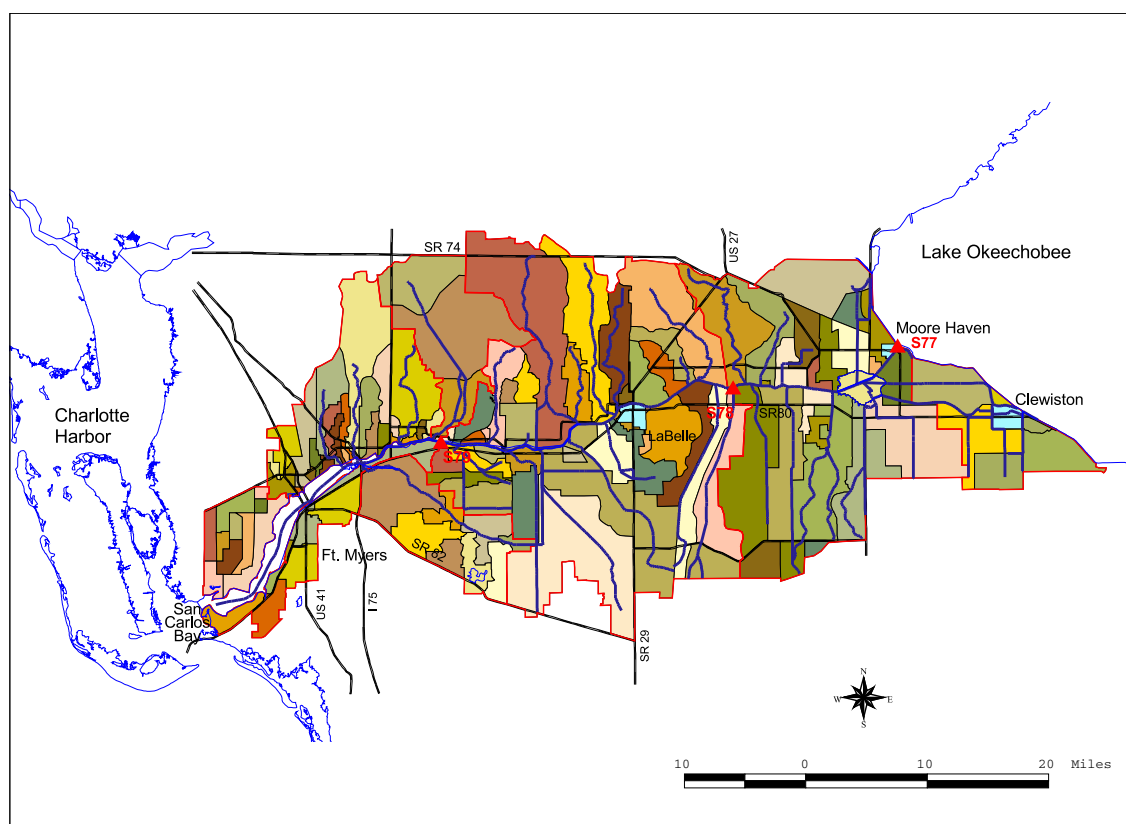
Figure J-2. Subbasins within the Caloosahatchee Basin.

coverage provides a basis for evaluating the changes in drainage that have occurred in the basin.

METHODS

Irrigation and drainage information was obtained from USACE reports, SFWMD coverages and engineering reports, drainage district reports, and consultant reports. Water use and drainage information will be compiled from the SFWMD's ORACLE and GIS databases. Many of the coverages used in this task were created by other organizations and obtained through SFWMD. Information on irrigation pumps was obtained from the SFWMD Water Use Division for parcels that had water use permits. Information for surface water drainage structures was extracted from the SFWMD surface water permits and reviewed with SFWMD Field Engineering Division staff. It was not possible to field verify the drainage and irrigation features and facilities. However, the locations were checked using aerial photography.

Two investigations of basin hydrography were completed and are presented as new coverages: 1) a study of natural drainage (predevelopment), and 2) a study of current hydrography. The predevelopment hydrography was constructed using information drawn from available historical documents. Flowpaths and significant hydrologic features are included in the coverage. Old flow paths were determined using USACE reports and

topography maps of the area prior to construction of the C-43 Canal. The resolution and detail of features were limited by details of the available information. It was not possible to verify this coverage, but the probable uncertainty associated with the features was documented.

DRAINAGE NETWORKS

There are few unaltered streams and sloughs in the basin. Pumps control the drainage in the eastern portion of the basin where there is little relief. Areas dominated by pump-controlled drainage include the S-4 Basin, the Disston Water Control District (DWCD) and the Flaghole Water Control District. Drainage in the remainder of Hendry County is controlled by conveyance in the major drainage canals. There are large sections of central Hendry County that do not have extensive drainage and drainage occurs as overland flow. These areas are subject to severe flooding that historically occurred in Hendry County. (USACE, 1953).

There is less developed drainage north of the river. West of Lake Hicpochee in Glades County there is much less intensive drainage. This area has greater relief than Hendry County and historically, less persistent flooding. However, there are many field ditches and ditched sloughs and marshes to encourage runoff. In the native landscape, there are large areas where drainage occurs primarily as sheetflow. The drainage network is notably less dense in these areas.

For Lee County, the drainage network is composed of several large canals that drain directly to the estuary. There are few drainage control structures because the drainage system was constructed to facilitate drainage and it was not designed for upstream head control. The drainage network in Lee County can be described in several sections including Lehigh Acres, Fort Myers, Cape Coral, transition subbasins along the estuary north of the river and east of SR 31, and the tributaries east of SR 31 to the Hendry County line. The drainage in Lehigh and urban Lee County south of the river has been primarily uncontrolled drainage. Drainage for Cape Coral is controlled in the freshwater zone by several weirs where runoff is captured and used to supplement treated water in a gray-water recycled water system. Runoff from the saltwater section is uncontrolled. The drainage in transition subbasins east of Cape Coral has been a serious problem. Although there are several bridges and culverts that affect drainage, there are no facilities that control head or discharge. There has been considerable small-scale urban development in these subbasins combined with redirected sheetflow from Cecil Webb Wildlife Management Area resulting in severe flooding near the river. East of SR 31 there are several small native streams on the north side and the south side of the river. These streams convey drainage from developed land to the river. The drainage from the developed land often exceeds the conveyance capacity of these small streams. Historically there was considerable flooding away from the river.

Source Areas

The drainage network was developed to describe the flow paths for runoff from source areas to the Caloosahatchee River. The source areas are where runoff begins. These areas are parcels where sheet flow becomes concentrated flow and forms define channels. For hydrologic analysis, the delineated source areas should produce uniform runoff as a result of a single land management and homogenous soil.

Land Use

The basin consists of more than 300 land use/land cover categories. These categories are a complex combination of land use, land cover, and land management practices. The categories range from wetlands such as marshes and sloughs, which are defined by land cover, to various urban classes such as commercial land subclasses that are defined by primarily by land use activities. Agricultural land is best characterized from hydrologic analysis based on the land management practices. An example of these is presented for the LaBelle 7.5 minute quadrangle (**Figure J-3**). The various land use categories can be combined to form classes that have relatively uniform hydrologic behavior. For example, the land use classes can be combined to form 17 land use classes that are presumed to behave in a hydrologically distinct manner (**Figure J-4**). As such they are a combination of land use and land cover. These classes differ in surface water storage and runoff characteristics, and expected evapotranspiration. The areal extent of the source areas varies greatly among the land use categories; urban land uses have small areal extent, while rural land uses cover large areas.

Where the land use classification is used to form distinct categories for hydrologic modeling it may be necessary to combine the land use types into categories that are substantially different. This has been done for the LaBelle quadrangle (**Figure J-4**). This classification reflects the difference in land use but not potential differences in land management practices..

Soil Types

The characteristics of surface runoff, total volume of runoff and peak runoff rate, are affected by the soil and site properties. There are two sets of factors that influence surface runoff: soil physical properties such as soil texture and depth to an impeding layer; and site factors such as slope and drainage density that determine offsite drainage. The soils are generally sandy with a layer that impedes percolation of water at various depths. The sandy surface soil has a high permeability that results in little runoff unless the water table aquifer reaches the ground surface. The impeding layer, consisting of clay, organic material or rock, restricts deep percolation resulting in high water tables and runoff. Shallow and less permeability impeding horizons result in greater potential runoff. There are many soil mapping units in the basin (e.g., **Figure J-5**). From a hydrologic perspective, these soils vary primarily in the thickness and texture of the surface horizon and the depth and permeability of the subsoil. For the range of soils found in this basin, there is a 30 percent range in variability of potential runoff based on hydrologic simulation (Flaig et al., 1998b). However, most of the soil series in the basin have a runoff potential
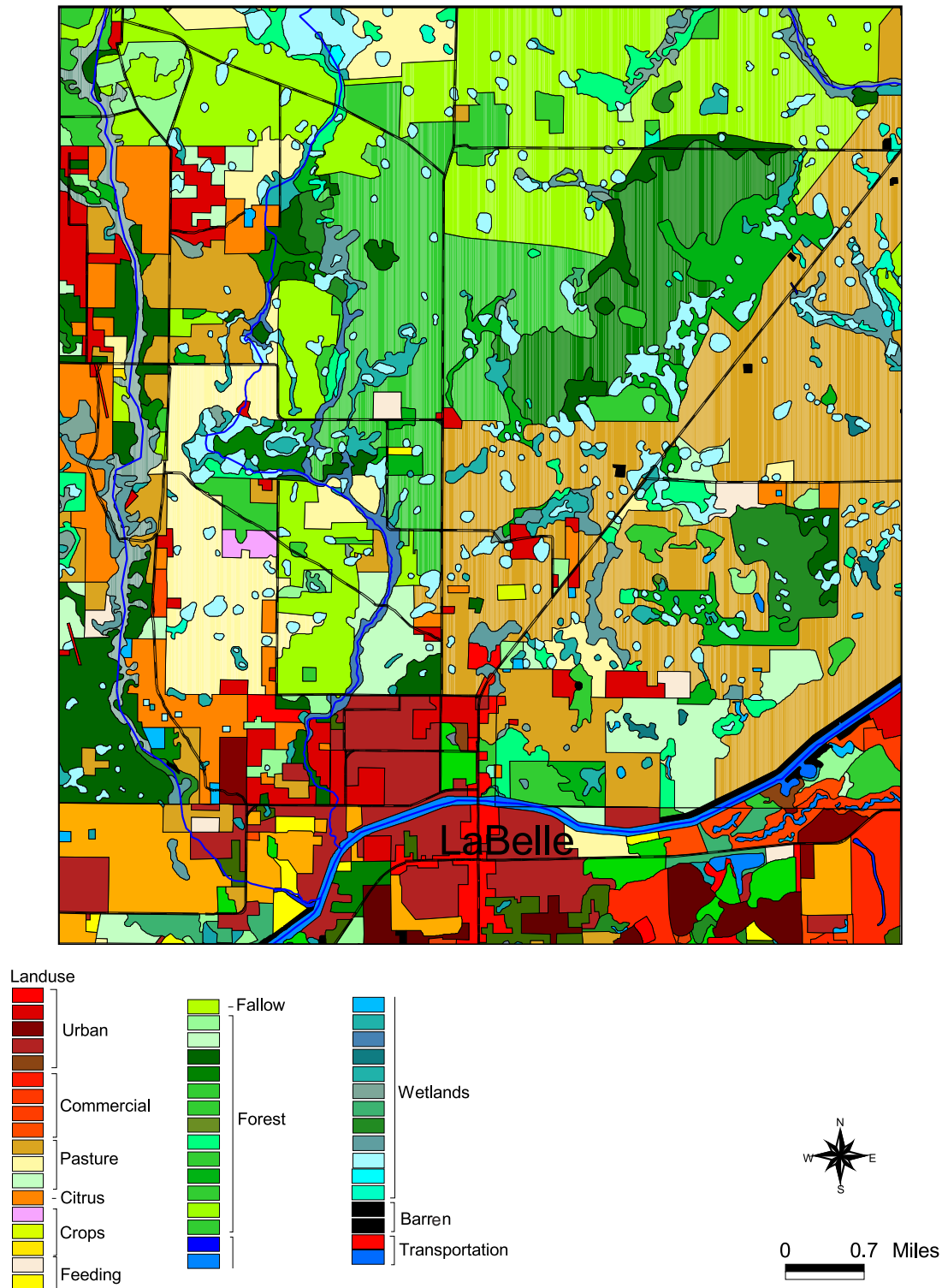
Figure J-3. Land Use Classification of the LaBelle 7.5-Minute Quadrangle.

Landuse

■ Sugarcane		■ Flatwoods	
■ Truck Crops		■ Mixed Hardwoods	
■ Dairies		■ Range/Scrub	
■ Citrus		■ Urban-Open	
■ Improved Pasture		■ Urban	
■ Unimproved Pasture		■ Swamps	
■ Water/Barren		■ Marsh	

0   0.6 Miles
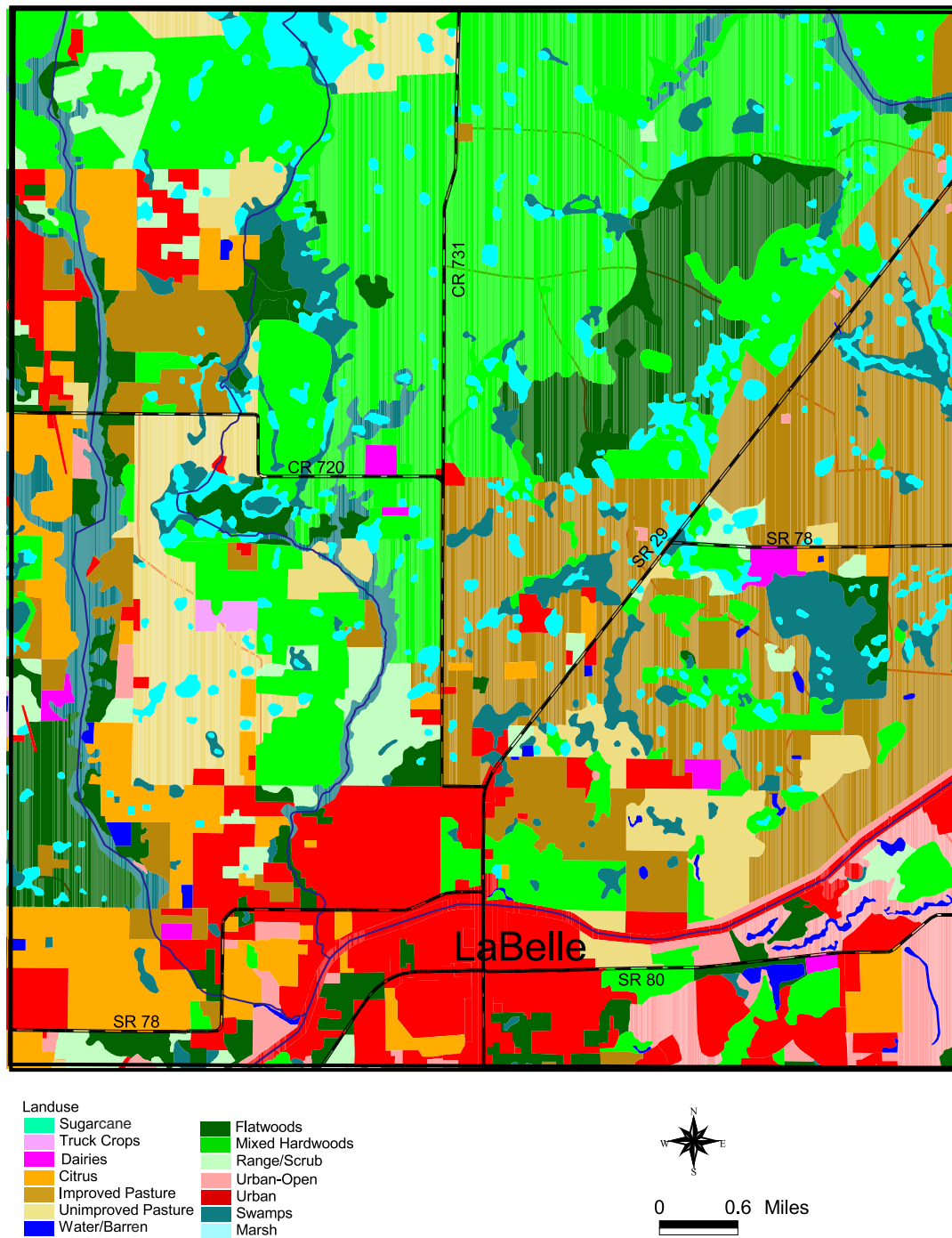
Figure J-4. Land Use Categories Grouped by Similar Land Use, Land Cover, and Land Management Practices.

Legend:

- ARENTS, VERY STEEP
- ASTOR FINE SAND
- BASINGER FINE SAND
- BASINGER FINE SAND
- BOCA FINE SAND
- CHOBEE LOAMY FINE SAND
- EAUGALLIE FINE SAND
- FELDA FINE SAND
- FLORIDANA FINE SAND
- FLORIDANA, ASTOR, AND FELDA SOILS
- GATOR MUCK
- HALLANDALE FINE SAND
- HALLANDALE-POPLE COMPLEX
- IMMOKALEE SAND
- MALABAR FINE SAND
- MALABAR FINE SAND, HIGH
- MYAKKA FINE SAND
- OKEELANTA AND DANIA MUCKS
- OKEELANTA MUCK
- OLDSMAR FINE SAND
- PINEDA FINE SAND
- POMELLO FINE SAND
- POPLE FINE SAND
- SANIBEL MUCK
- SMYRNA FINE SAND
- TERRA CEIA MUCK
- VALKARIA FINE SAND
- WATER

0   0.8   Miles

Figure J-5. Soil Mapping Units for the LaBelle 7.5-Minute Quadrangle.

that varies less than ten percent different based on internal soil physical characteristics. This suggests that the most of the soils in the basin are not substantially different.

Landscape

The soils mapping units can be combined to form soil groups that respond in a hydrologically similar manner (**Figure J-6**). The landscape classes, define by National Resources Conservation Service (NRCS) for range land productivity, provide a scheme for defining landscape drainage according to vegetation type. The vegetation types correspond to the annual period of inundation and persistence of high water tables following rainfall events. In sandy soils, the landscape drainage is the most important factor affecting runoff potential. The landscape classes are generally indicative of the flowpaths in the basin.

Wetlands

The wetlands are closely associated with the depressional soils (**Figure J-7**). There are two sources of information for the spatial distribution of wetlands, USGS hydrography and the National Wetlands Inventory. When overlaid both sources indicate a wide distribution of wetlands. The wetlands consist of continuous sloughs and isolated emergent marshes. Most of the isolated marshes do not appear to be part of the drainage network.

Development of Drainage Networks

The drainage network delineates the areal pattern of storm water runoff and shallow ground water drainage in the basin. A drainage network describes the flowpath that water takes from the point of origin of overland flow or discharge from an impoundment to the receiving water body. The drainage network consists of the ditches, streams, sloughs, and marshes that constitute the drainage paths to the Caloosahatchee River. By definition, the network must connect the structures that control drainage from farms and urban developments. The drainage network is used to delineate the basin and subbasin boundaries. The network also is used for hydrologic and hydraulic simulation model development. The accuracy and precision of the drainage network depends on the quality and availability of the source information. Although positional accuracy is important, the connectivity of the network is critical to modeling applications; each flowpath must connect in the correct order and the drainage facilities must be connected at the appropriate point in the network.

The drainage networks were developed to describe the flowpaths from runoff source areas to the Caloosahatchee River. Each drainage network was developed to provide a single flowpath for runoff resulting in a simple dendritic pattern. Where there were multiple ditches providing drainage to the same parcel, the parcel was divided with each ditch draining a unique section. Where a parcel with multiple outlets was less than 30 acres, the primary drainage was selected and the other drainage paths were deleted. Parcels were defined as areas of homogenous land use or homogenous land management.
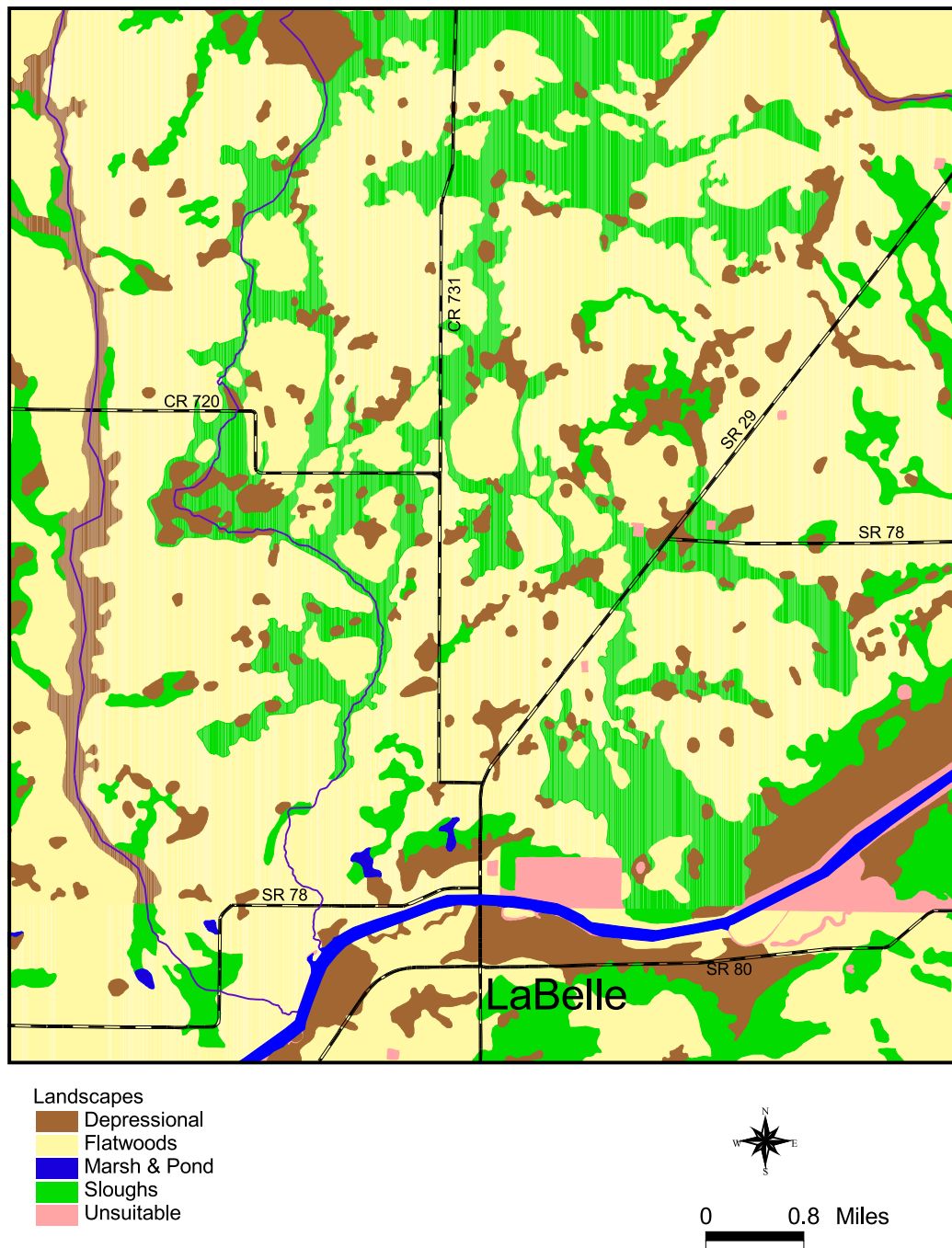
Figure J-6. Landscape Classes for the LaBelle 7.5-Minute Quadrangle.
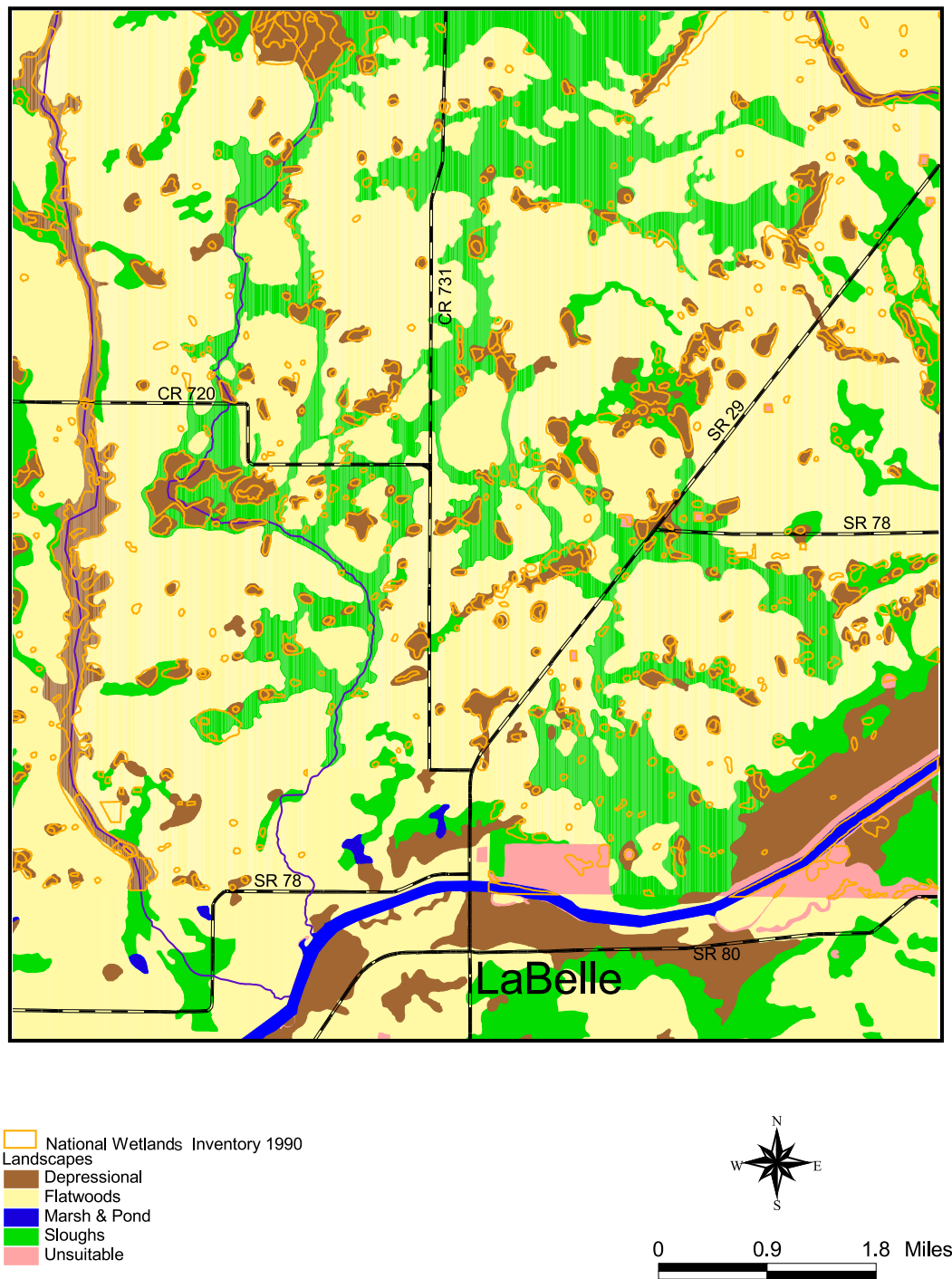
Figure J-7. Wetlands and Landscape Classes for the LaBelle 7.5-Minute Quadrangle.

The drainage network was designed to provide a simplified description of the drainage for all parcels greater than 30 acres. The network does not contain all ditches, streams and other flowpaths in the basin. For example, many farm ditches and urban drainage ditches have not been included because they represent additional drainage for a parcel or they are internal to a parcel where a drainage control facility is located downstream. In these cases, only the primary drainage flowpath was included and the remaining ditches were used to determine the drainage coefficient (inches per day [in/day]) for the parcel.

The drainage network was developed based on the native hydrography, wetlands, soils, and man-made hydrography. The 1:24,000 scale coverage for the Fort Myers 1:100,000 quadrangle region was used in this task (**Figure J-8**). Additional sections were included from the Naples and West Palm Beach quadrangles. The hydrography contained the isolated wetland, streams, ditches, and shorelines of extensive wetlands.
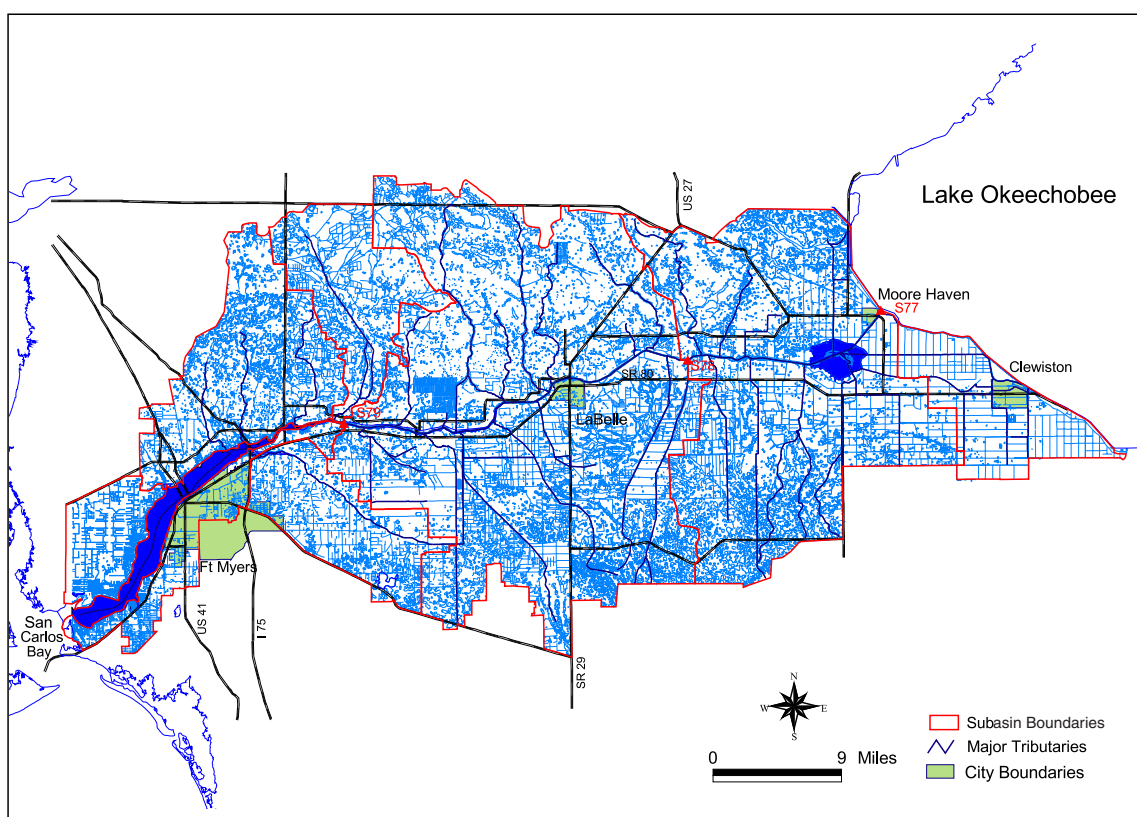
Figure J-8. Hydrography of the Caloosahatchee Basin.

It was expected that the published hydrography would be sufficient to define the drainage network. Unfortunately, the current hydrography coverage did not contain sufficient information to develop the drainage network in the basin. The hydrography coverage did not include the flowpaths through marshes or sloughs, it only indicated the shorelines (**Figure J-9**).   The hydrography also did not include flowpaths through wet prairies or indicate the location of shallow field ditches. It was necessary develop a more detailed drainage network based on reviewing the 1994-5 infrared aerial photography. It was possible to determine the additional ditches and areas of concentrated flow from the

Topographic Divisions

0'	
5'	35'
10'	40'
15'	45'
20'	50'
25'	55'
30'	60'

0   0.7   Miles
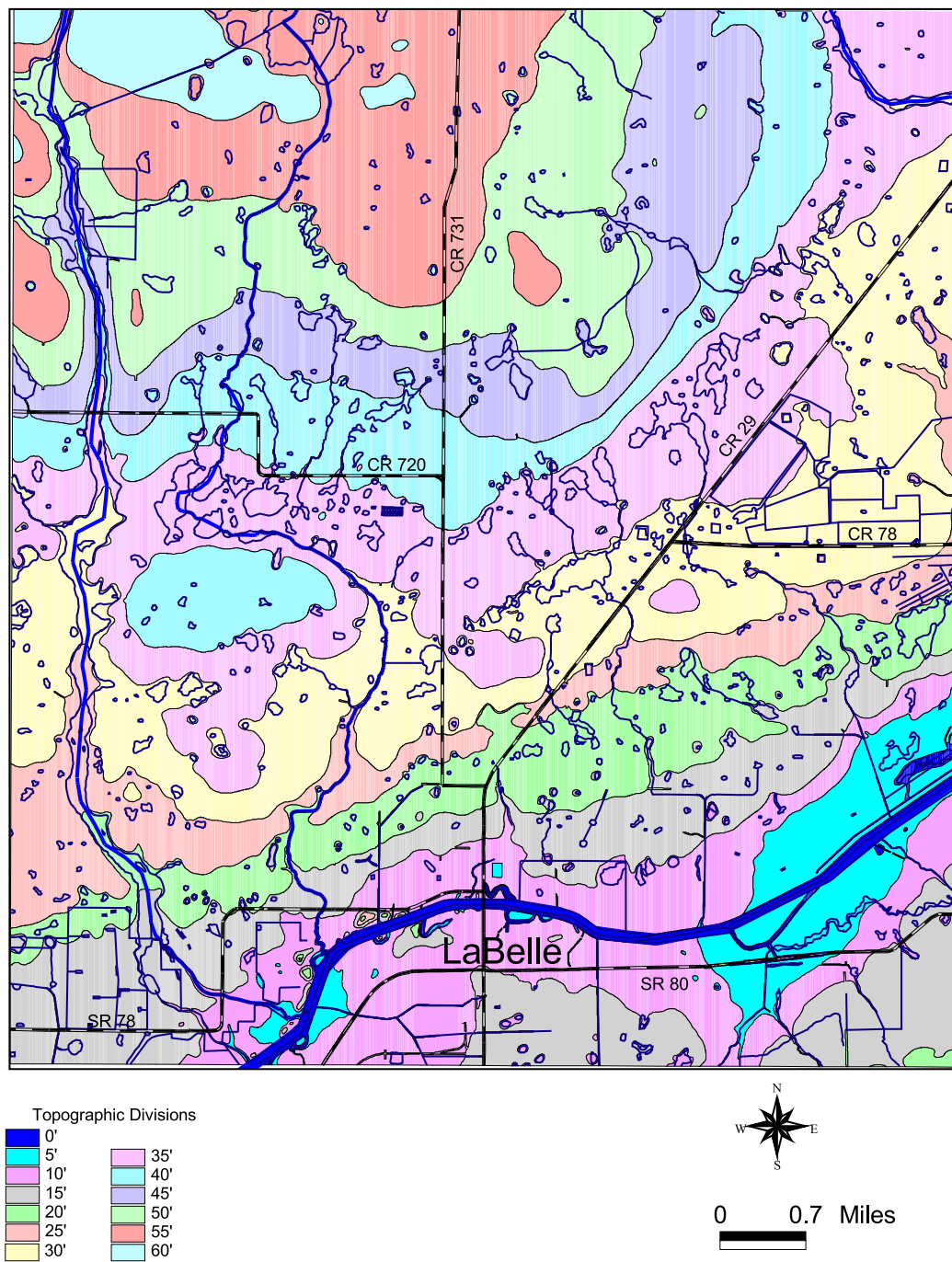
Figure J-9. Topography and Hydrography of the LaBelle Quadrangle.

aerials. Flowpaths that drained substantial areas were identified and combined with the current hydrography. The process of identifying and defining the flowpaths resulted in development of drainage network.

In addition to reviewing the aerial photography, other information such as geology, wetlands, soils, and structural information concerning roads and culverts was used to develop the drainage network. The effect of surficial geology on runoff in the Caloosahatchee Basin has not been quantified. Throughout most of the basin the surface formations consist primarily of sand with shell and clays below 6 feet. West of LaBelle there is a greater occurrence of clay lenses and marl rock is found near the surface. Greater runoff is expected from areas with fine textured soils while less surface runoff is expected where fractured marl exists. There is a greater density of native streams west of LaBelle. There are fewer streams near the river where marl is shallow and there appears to be greater shallow ground water flow.

Surface relief influences the concentration of overland flow, the direction of streams and density of creeks. The relief in the Caloosahatchee is parallel to the river with little tributary valley formation (**Figure J-10**). There are high points on the north side at 78 feet NGVD and on the south side at 42 feet NGVD. There are large areas in the basin that have very low relief. There are several north-south oriented sloughs along the river indicated by the bold lines in **Figure J-10**. However, the topography provided little help in identifying the drainage flowpaths. The topographic data currently available in electronic form describes 5-foot contours. This information was useful in identifying/ verifying the major drainage flowpaths (**Figure J-11**). The small undulations in the contour lines were consistent with the location of the drainage flowpaths. However, this did not provide sufficient information for connecting the various wetlands and source areas. One-foot contour maps were available in paper form (War Department, 1935; JP, 1953). The 1-foot contours were compared to the 5-foot contours. The 1-foot contours essentially were parallel to the 5-foot contours with few additional undulations. This is not surprising given the predominance of sandy soil and the lack of bedrock. Although the topographic data was useful for identifying major drainage paths, it was not useful for identifying the detailed drainage flowpaths.

There are a substantial number of wetlands (National Wetlands Inventory, 1990) in the Caloosahatchee Basin (**Figure J-12**), and these were used to identify, and verify the location of flowpaths determined using aerial photography. It was expected that the many of the wetlands would be connected and form a major component of the drainage network. However, a large portion of the wetlands are disconnected (**Figure J-13**). The distribution of the wetlands does not follow the general relief; there are groups of wetlands at some elevations but not at other elevations. The wetlands do not appear to be related to the topography, either 5-foot intervals or 1-foot intervals (not shown). Although the wetlands do not provide a connected network, the network does contain many of the wetlands (**Figure J-13**).

The landscape classes (described above) provide another source of geospatial information for verifying the location of the hydrography. The depressional and slough classes generally follow the pattern of the wetlands but are more connected than the
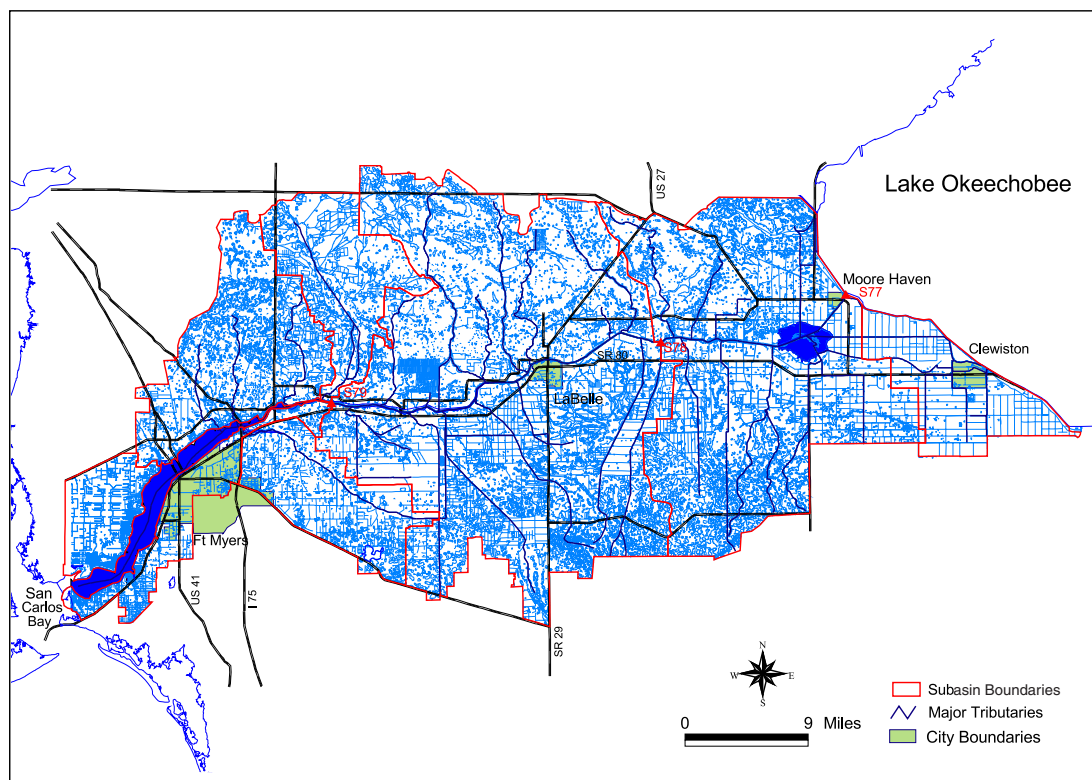
Figure J-10. Topography of the Caloosahatchee Basin.
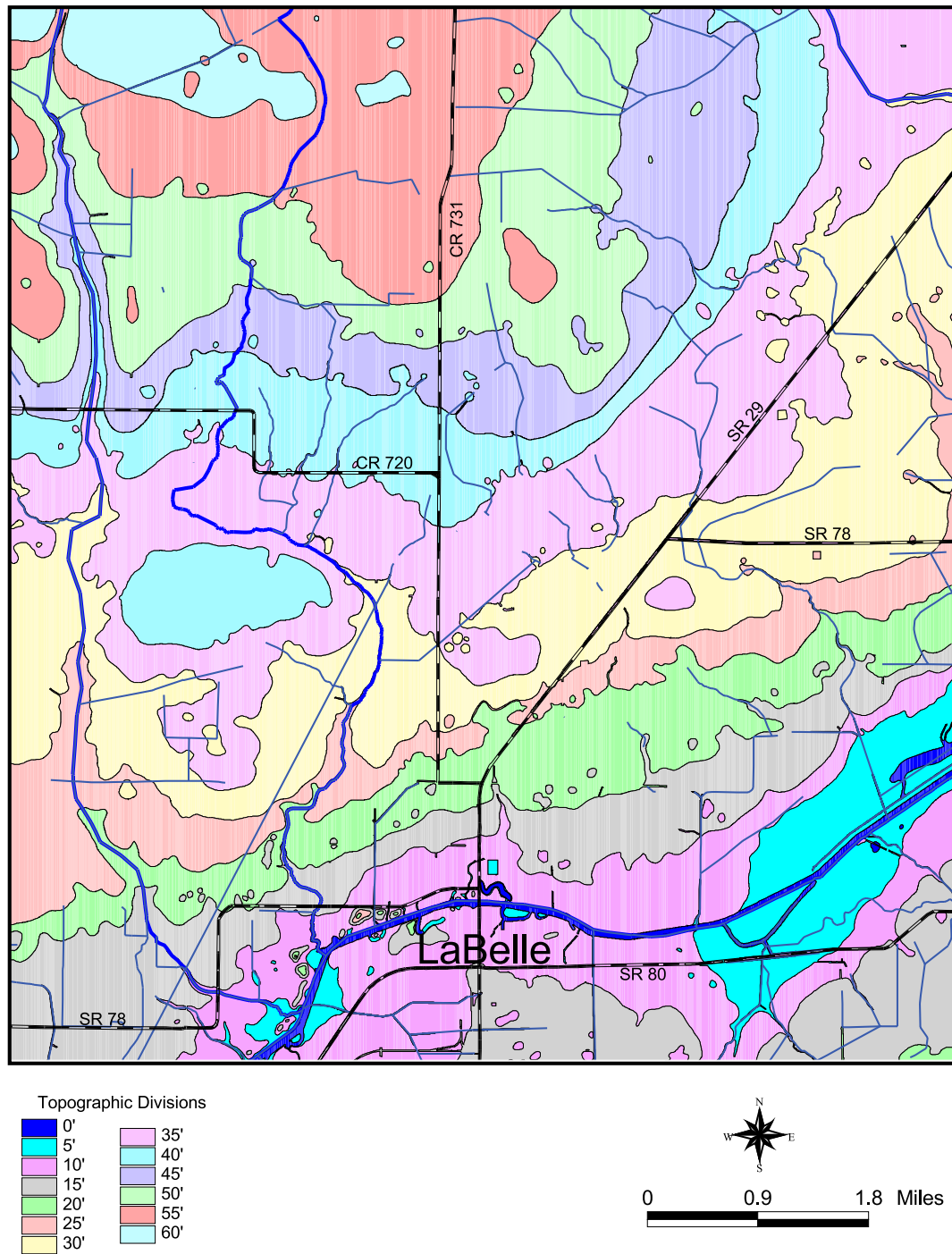
Figure J-11. Drainage Network and Surface Relief for the LaBelle Quadrangle.
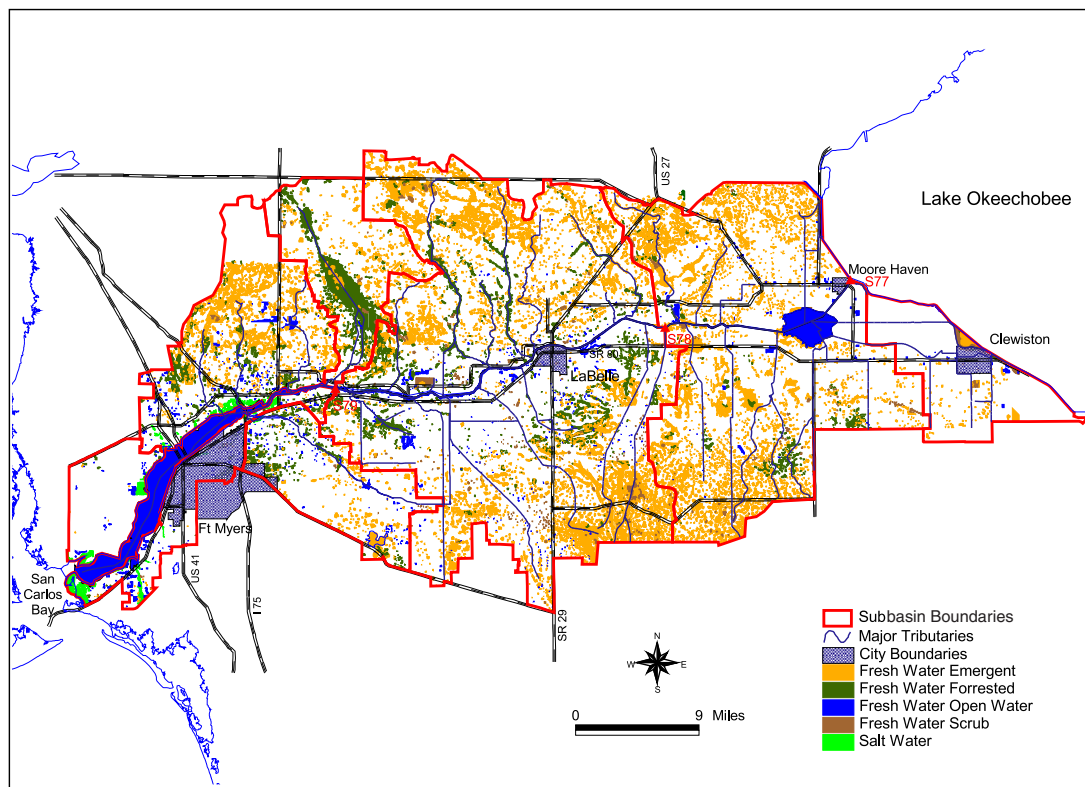
Figure J-12. Wetlands of the Calooshatchee Basin.
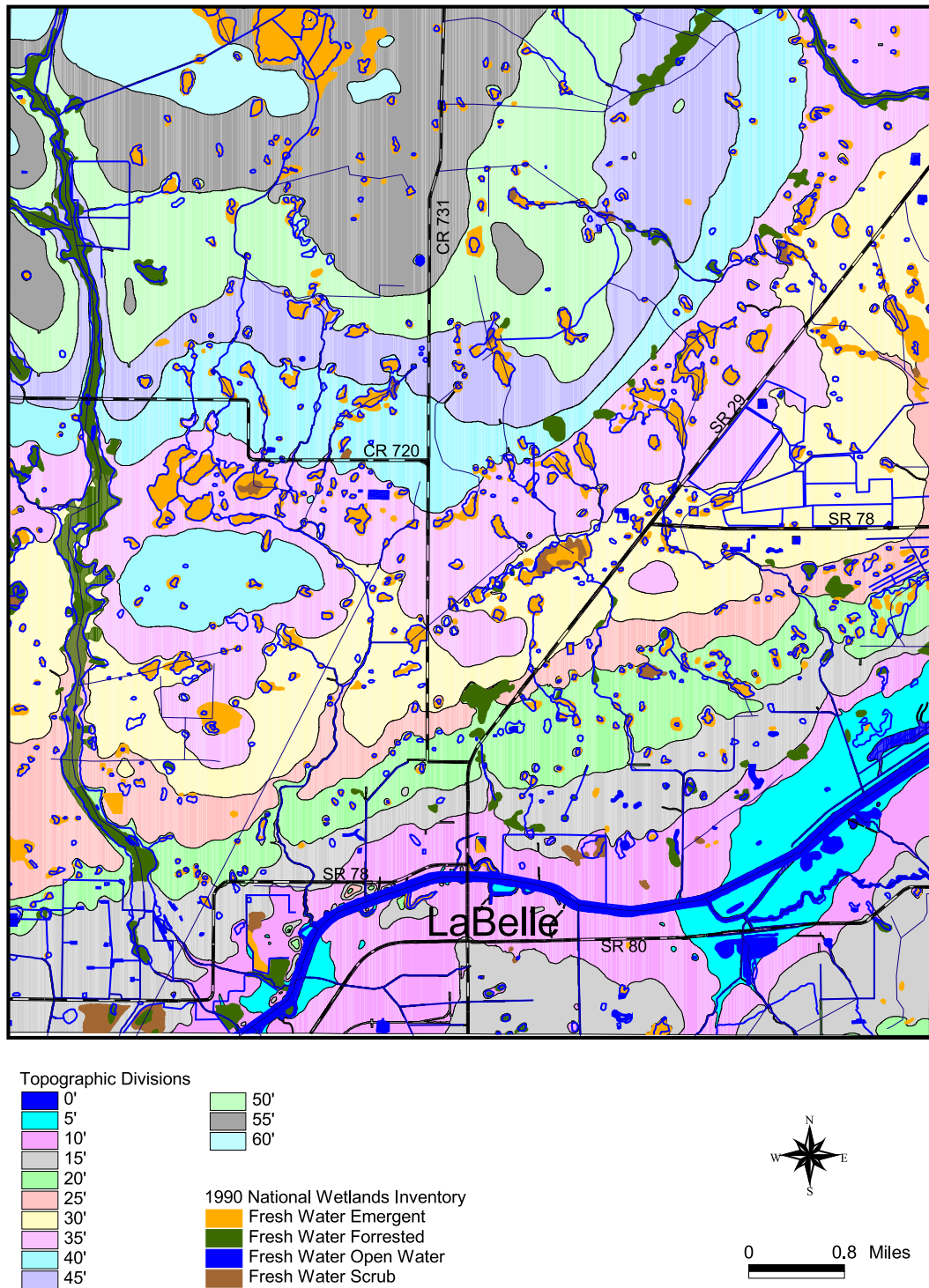
Figure J-13. Drainage Network and Wetlands for the LaBelle Quadrangle.

wetlands (**Figure J-14**). In general, the sloughs run along the primary flowpaths, perpendicular to the relief. However, there are several areas in the basin where the land is flat and the sloughs do not coincide with the apparent flowpaths. In these locations, there is seasonal flooding and additional drainage ditches have been dug. The depressional soil and particularly the slough soils connect the wetlands and are consistent with the drainage network developed from the aerial photographs (**Figure J-15**). Although the wetlands, landscape classes, and hydrography coverages could be used to identify and verify a consistent drainage network, the location of the network is limited by the positional accuracy of the coverages. As shown in **Figure J-16**, the same landscape features from different coverages are offset and often slightly different in shape.   The relative uncertainty will be discussed in the Task 6 report (Flaig et al., 1998c).

Drainage Network Attributes

Attributes were added to the line coverage to describe the type of conveyance for each flowpath in the basin. The flowpaths were categorized as one of 15 possible flowpaths (**Figure J-17**) based on the size, degree of channelization and vegetation. The first level of classification was based on connectivity: isolated, partially connected, or fully connected. The second level of classification was based on vegetation type which affects water use, resistance to flow, and potential water storage. The third level of classification was based on the degree of ditching. Many native wetlands have been ditched to improve conveyance and to lower the local water table.

Isolated Ponds

These are not flowpaths as such because they are isolated. However, at high water levels they may become part of the concentrated overland flow.

Ponds

These are open-water flowpaths. The ponds may be native or have ditches through them to improve conveyance.

Marshes

Marshes are wetlands containing emergent aquatic macrophytes.   These are depressional areas, which remain wet during the summer and often dry-out during the dry season. Marshes are broad and shallow with no defined flowpaths. At high water levels, the marsh vegetation tends to bend over and provide a more open flowpath with substantially less resistance to flow. Marshes may be channelized to improve drainage and to lower the local water table. The flow characteristics of the marsh depend on grazing pressure, nutrient load, and hydroperiod.
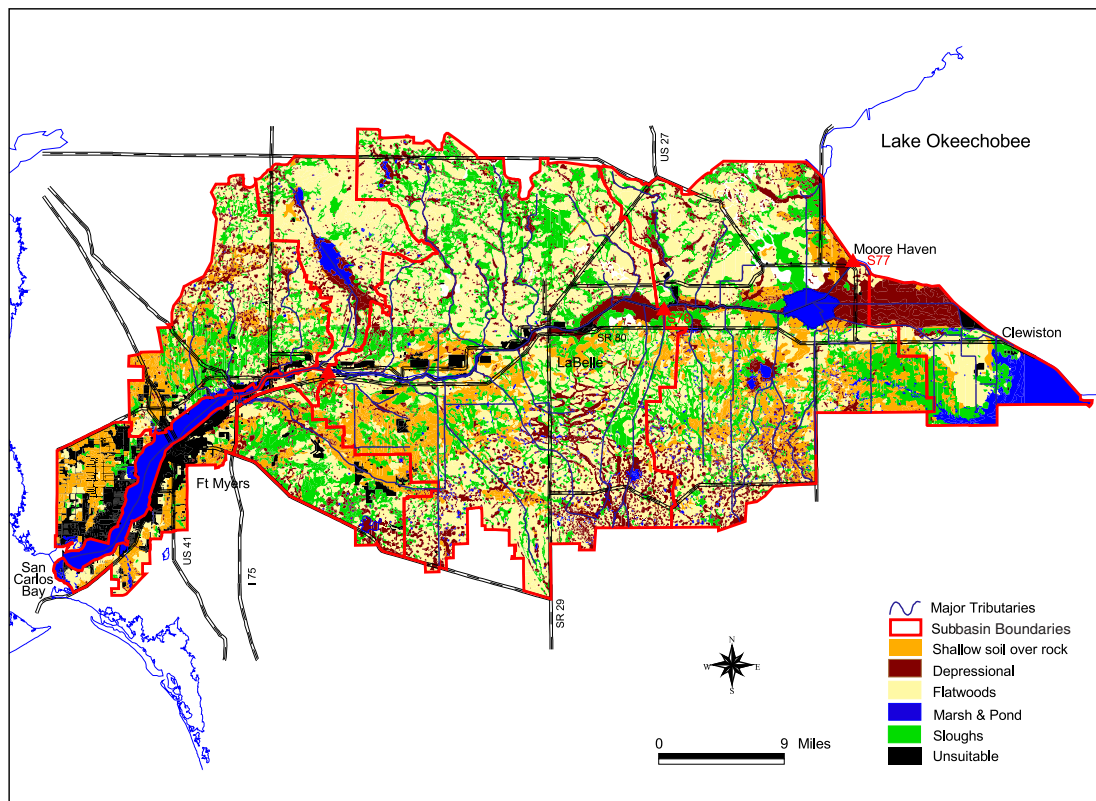
Figure J-14. Soil Landscape Groups for the Caloosahatchee Basin.
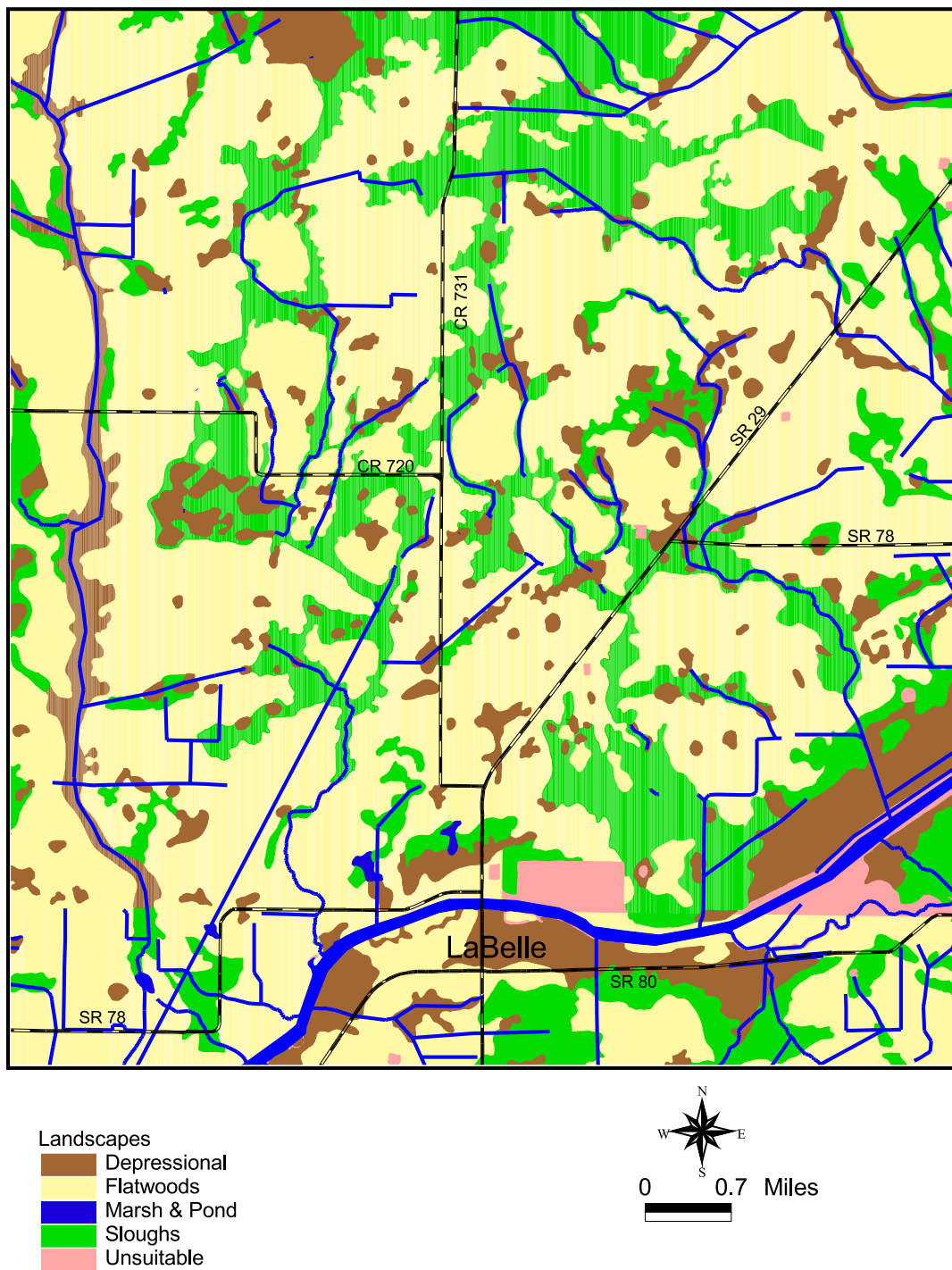
Figure J-15. Landscape Classes and Drainage Network for the LaBelle Quadrangle.
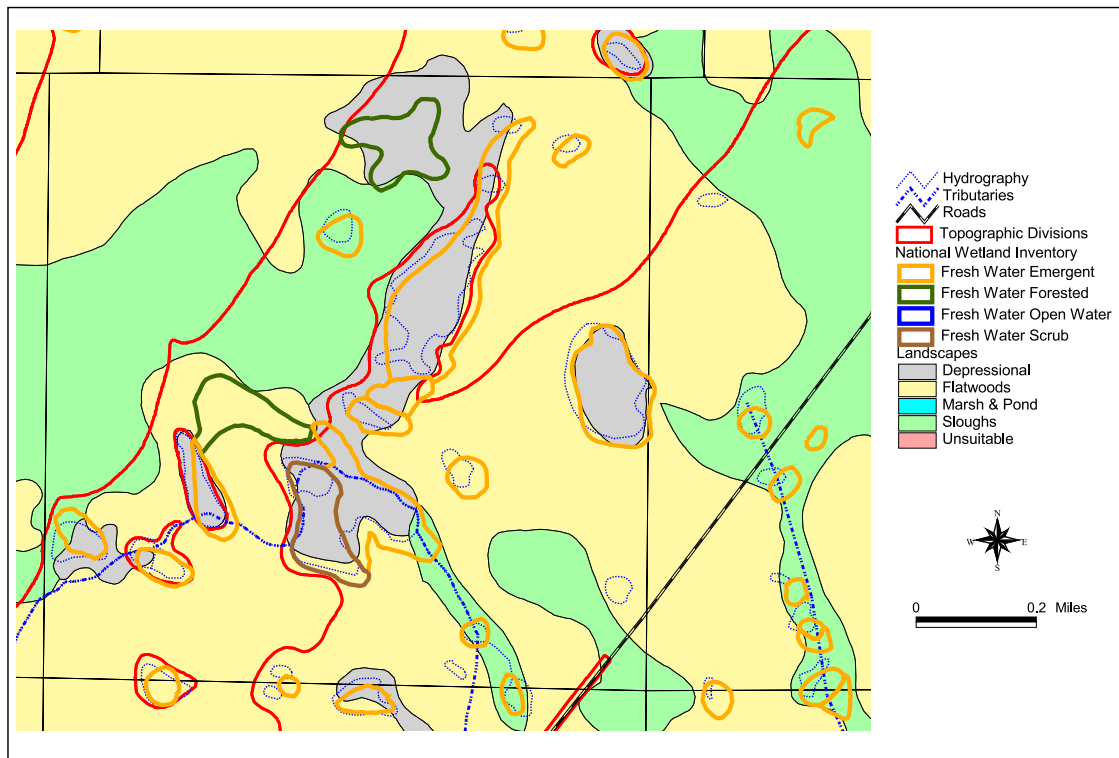
Figure J-16. Landscape Classes, Hydrography, Wetlands, and Tributaries for Section 2, T42S, R29E.

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                                      ┌──────────────┐
                                      │   Wetlands   │
                                      └──────┬───────┘
              ┌───────────────┬──────────────┴───────────────────────┐
      ┌───────┴──────┐ ┌──────┴───────────┐              ┌────────────┴────┐
      │   Isolated   │ │ Partially Connected│            │   Connected    │
      └───────┬──────┘ └──────┬───────────┘              └────────┬────────┘
      ┌───────┴──────┐ ┌──────┴───────────┐              ┌────────┴─────────┐
      │   Ponds      │ │ Marshes, Swamps  │              │ Streams, Ditches,│
      │    (1)       │ │ Wet Prairies     │              │ Canals, Sloughs  │
      │ Marshes, Ponds│ │                 │              │                  │
      │ Cypress Domes │ │                 │              │                  │
      └──────────────┘ └──────┬───────────┘              └────────┬─────────┘
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Figure J-17 diagram:

- **Wetlands**
  - **Isolated** → Ponds (1), Marshes, Ponds, Cypress Domes
  - **Partially Connected** → Marshes, Swamps, Wet Prairies
    - Marshes → Native (2), Ditched (14)
    - Ponds → Native (3), Ditched (15)
    - Swamps → Native (4)
    - Wet Prairies → Native (5)
  - **Connected** → Streams, Ditches, Canals, Sloughs
    - Sloughs → Native (6), Ditched (7)
    - Streams → Native (8), Ditched (9)
    - Ditches → Field (10), Farm (11), Road (12), Canal (13)

Figure J-17. Flowpaths in the Caloosahatchee Basin.

Swamps

Swamps are wetlands containing cypress or hardwood trees. These are depressions that remain wet most of the year. Swamps are similar to sloughs with the exception that the natural gradient is less than a slough and there is less flow. Sloughs have a well defined flowpath and floodplain.

Wet Prairies

Wet prairies are large areas of pasture, scrub, or flatwoods where there are few ditches, streams, or other conveyance paths. The flowpaths are primarily overland flow with few concentrated flowpaths. The density of the vegetation depends on grazing pressure where these lands are used for pasture.

Sloughs

Sloughs are forested wetlands with wide and shallow flowpaths. The common vegetation is swamp cypress or mixed cypress and hardwoods. The typical cross-section of the flowpath is primarily large stems with little ground cover or underbrush. Often there is a small natural channel through the slough and the remaining portion behaves as a floodplain. In several sloughs, a channel has been cut to increase conveyance capacity and lower the control elevation to encourage drainage of adjacent uplands.

Streams

Streams are native flowpaths primarily through uplands. They differ from marshes and sloughs as narrow and well defined flowpaths with limited floodplains. The native streams often are sinuous because of the low gradients in the basin. They may be discontinuous and connected to swamps and sloughs. The streams (and creeks) range in size from 3 feet to 10 feet in width. In several locations, native streams have been ditched to increase conveyance and reduce backwater effects. The ditched streams have dimensions similar to farm ditches.

Ditches

There are several varieties of ditches ranging in size from the shallow grader swale used to drain small depressions to large conveyance canals used for regional irrigation or drainage. The key characteristics of the ditch classification are that they were dug for specific conveyance and are not related to existing wetlands. The ditches have been delineated into one of the following four types: field ditches, farm ditches, road ditches, and conveyance canals.

Road Ditches

Road ditches may vary in shape from broad grassy swales to deep ditches. The vegetation in the ditches may vary from short, mowed grass to dense shrubbery. The road ditches may be designed or intended for drainage conveyance or a shallow, lateral

detention area. The county road crews periodically clean the road ditches. As such, it is not possible to define a consistent flowpath. However, road ditches provide an important flowpath at high water levels.

Road ditches also provide important connections where the roads form basin boundaries. In many places roads define high, flow dividing obstacles. The road ditches collect runoff and redirect it through culverts into primary drainage flowpaths. These ditches are important collector systems.

Field Ditches

Field ditches include shallow ditches intended to drain small areas and provide limited drainage. These ditches are generally less than 3 feet deep and less than 6 feet wide. They are constructed to allow crossing by field equipment. They are intended to drain excess surface water and have a minor impact on the water table. These ditches are ephemeral flowpaths depending on their position on the landscape. They may be clean or filled with emergent aquatic vegetation depending on grazing pressure.

Farm Ditches

Farm ditches are large ditches that provide conveyance for drainage or irrigation for entire farms. The defining property is the conveyance capacity. Farm ditches are generally greater than 4 feet deep and intended to be sufficiently deep to discourage the growth of emergent aquatic macrophytes that would restrict flow. These ditches are greater than 10 feet wide but less than 50 feet wide. Unlike field ditches that are primarily intended to provide surface water drainage by lowering the control elevation, farm ditches produce a long-term lowering of water table.

Canals

There are several canals in the basin. These canals were designed to provide drainage conveyance. The canals are large features with widths greater than 50 feet and often greater than 100 feet with depths up to 15 feet.

It was not possible to determine the dimensions of specific flowpaths. Few records are available that describe the dimensions of the constructed ditches and canals. The canals were built using standard designs. The ditches have changed as a result of growth of vegetation, accumulation of organic sediment, and sidebank erosion over time. The ditches have been cleaned out periodically by the county and private maintenance crews at irregular intervals. As a result, the dimensions of road ditches and canals are variable and imprecise. Although the various drainage and irrigation canals were dug to meet specific dimensions, the current configuration of these canals is uncertain due to erosion and sedimentation processes. Not only are the dimensions uncertain, but also the slope and the roughness of the various flowpaths are uncertain. The roughness factor (Manning's n) is an important parameter in hydrologic modeling, and variation in this parameter is large because of variation in vegetative growth in the flowpaths.

Caloosahatchee Tributary Coverage

The Caloosahatchee tributary coverage (CALTRIB) was derived from the standard 1:24,000 hydrography coverage for the Fort Myers quadrangle. The coverage was modified to describe additional flowpaths that were not in the hydrography coverage. An additional attribute "attribute" was added to the arcs to describe the flowpath type. The value for "attribute" may range in value from 1 to 15. The chart of the attributes illustrating the classification scheme is provided in **Figure J-17**.

Drainage Structures

The drainage network connects the source areas for surface water runoff with the Caloosahatchee River. An important component of the drainage network is the coverage of drainage control structures. There are many agricultural and urban developments that have surface discharge structures that regulate off-site discharge (**Figure J-18**).

The drainage control structures are an important component of the drainage network. The basin has been substantially altered by agricultural and urban development. Each development has a surface water permit that permits a discharge structure that allows discharge at a rate not to exceed the predevelopment peak runoff rate or volume of runoff. The principal drainage structures in the basin were tabulated from surface water permits, water control district reports, and consultant reports. The surface water permits were reviewed at the SFWMD offices in Fort Myers and West Palm Beach. The characteristics of each discharge structure, dimensions, and control elevations (where available) are provided in the Appendix.

Throughout the rural portion of the basin, most of the water control structures are associated with agricultural development. In particular, most of the control structures are discharge structures for detention ponds for citrus groves. There are few detention ponds associated with sand land sugarcane. Groves established before 1984 do not have detention facilities and the control structures, either simple culverts or drop-structures with flash-board risers, are located on farm ditches. The detention characteristics of these systems are uncertain. There are few water control structures on pasture land. Drainage on these sites is controlled by shallow field ditches and low elevation berms such as road grades. Discharge from these sites is controlled by the capacity of culverts and bridges. Although the field ditches satisfy local conveyance requirements, there is no design information available. On the large permitted parcels, few structures are presented in detail in the permitted design, only the final discharge structure is permitted and there is little available information on drainage structures internal to the parcel.

In Lee County, there are many structures such as bridges and box-culverts under roads that affect discharge but are not designed to control drainage. They are included in this summary because they are the only structures that affect flow in many subbasins, and during high flow they may cause significant backwater effects. Where there is a high degree of drainage (i.e., Lehigh Acres, Fort Myers, and Cape Coral) only the major structures have been included in the analysis. Upstream discharge is controlled by these
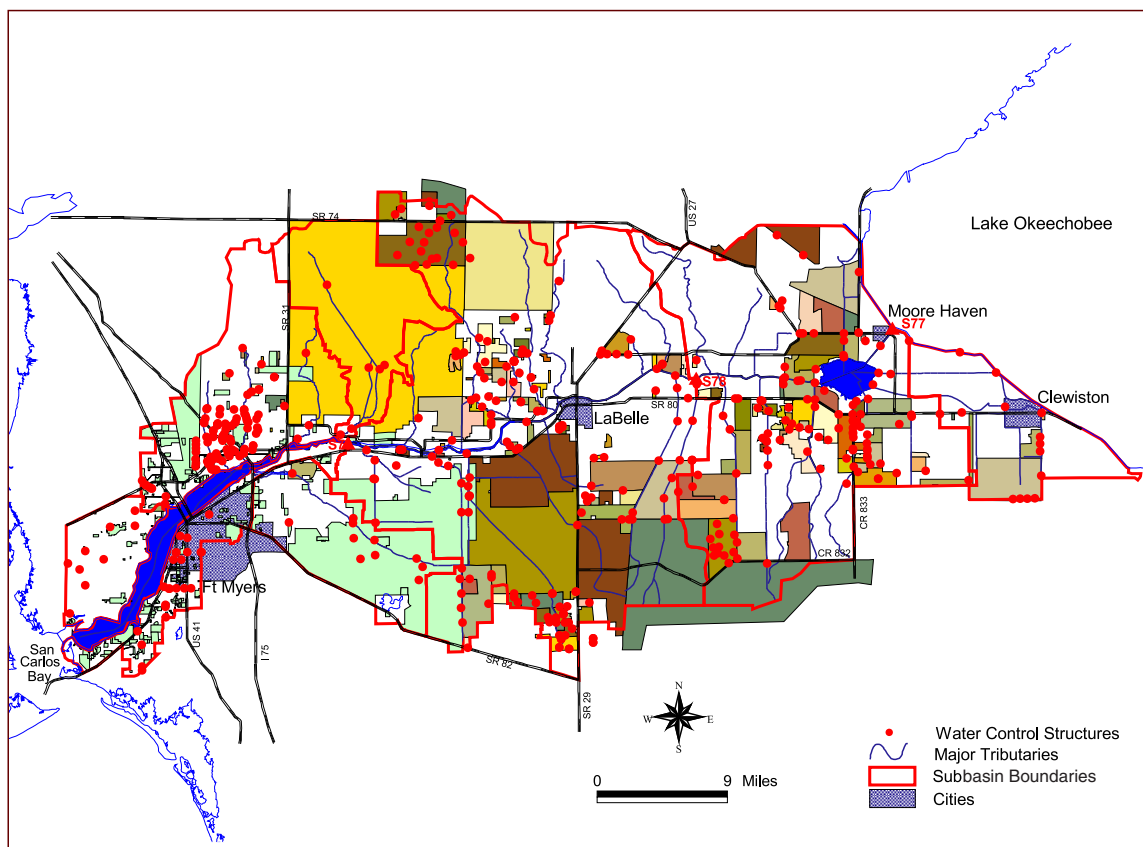
Figure J-18. Surface Water Permits for the Caloosahatchee Basin.

structures, and no additional information is gained by including upstream structures. In the transition subbasins northeast of Cape Coral, several structures are indicated on each tributary. Each of the structures are included because none of these structures appear to provide a flow-limiting control point.

The compiled set of primary, secondary, and permitted water control structures is presented in **Figure J-19**. The highest densities of control structures are found in the urban area, northwest of LaBelle and south of Lake Hicpochee. These are areas of small parcel ownership and limited drainage. The information from the permits was verified by consulting with District field engineering staff. Verification focused on structure location and operation because the permit files do not contain "as-built" information. It was not feasible to conduct field verification. The operating rule for each structure was defined as the allowable drainage rate for each surface water permit. The operational behavior for the large secondary canals is based on allowable drainage rate for the water control districts and maintaining the water levels in the water control districts. The operational rules are provided in the Plan of Reclamation for each water control district. Each plan of reclamation is a living documents that is updated by each water control district as needed and recorded at the county courthouse. Unfortunately, the plans are not compiled as single document and thus are not readily available.

Impoundments

Impoundments developed to detain or retain storm water runoff are important landscape features that affect water resource management in the Caloosahatchee Basin. The impoundments were developed as part of the surface water permits to meet the requirement to detain surface water runoff so that it does not exceed predevelopment runoff behavior. Although impoundments are an integral part of recent permits, they were not required for permitting older developments either urban or agricultural. As a result, there are large areas in the basin that have few impoundments (**Figure J-20**).

The impoundments affect both runoff behavior and water storage. Peak runoff rate and total volume of runoff are reduced when runoff is routed through the impoundments. Because many of these impoundments are not lined to prevent seepage, the delayed discharge from the impoundments may produce an increase in local ground water recharge where the ground water has been lowered for flood protection. This may result in more water for irrigation immediately following storm events.

On most sites, the impoundments were not designed to retain water and the seepage rates are high. In urban areas, the impoundments are constructed from borrow pits where fill material was removed for building sites. On agricultural sites the impoundments are commonly built as above-ground facilities with berms built from borrow material from inside the impoundment. In these above-grade facilities, water seeps through the berms into perimeter ditches as well as into ground water. There is some evidence that where the impoundment berms were designed and constructed using standard techniques for earthen dam construction, the impoundments can retain runoff.
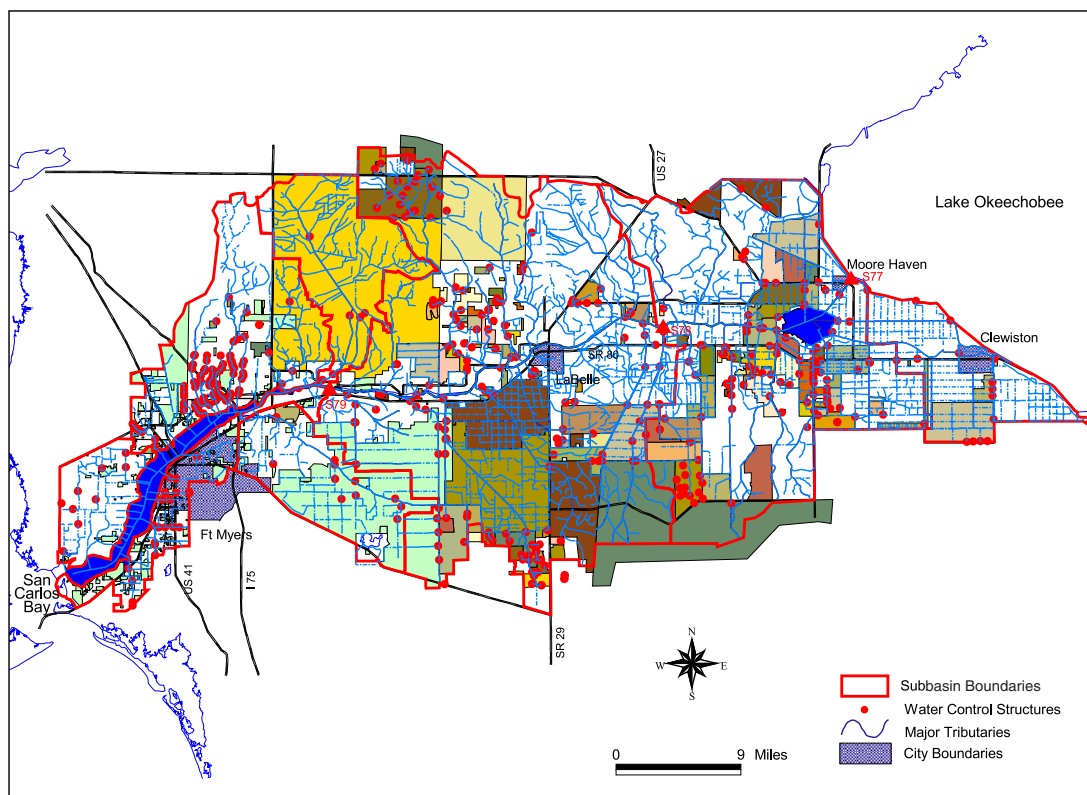
Figure J-19. Drainage Network and Surface Water Permits for the Caloosahatchee Basin.
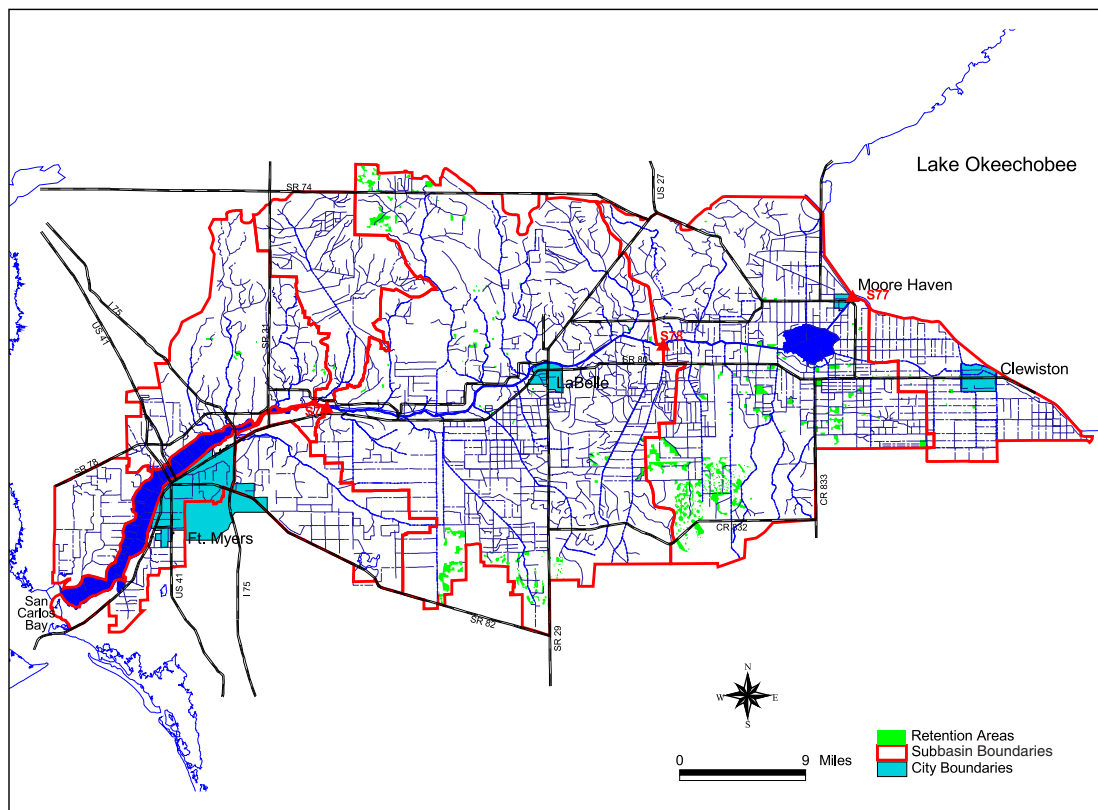
Figure J-20. Agricultural Impoundments in the Caloosahatchee Basin.

Impoundment Coverage

The impoundment coverage was developed primarily from irrigated-land coverages obtained from the Water Use Division, SFWMD (**Figure J-20**). These irrigated-land coverages delineated several types of impoundments including detention, retention, enclosed wetlands, and sloughs within each permit boundary in addition to the agricultural land. These coverages were developed from permit applications to provide a more accurate database from which to estimate water use demand. The impoundment coverage developed from the irrigated land coverages was not complete; there were many other impoundments not in the irrigation coverage and not associated with water use permits. These additional impoundments were digitized using 1994-95 infrared aerial photography, the 1988 SFWMD land use coverage, surface water permit coverages, and hydrography coverage and included in the coverage. The location accuracy of the impoundments is of the same order of magnitude as the accuracy of those coverages.

The impoundment coverage indicates that there are 14,000 acres of retention/ detention facilities in the Caloosahatchee Basin. Most of the impoundments occur along the north and south edges of the basin where more recent development has occurred. There is also a substantial acreage of impoundments located near Lake Hicpochee. There are few impoundments in the central area of the basin or along the river, because these agricultural developments are older and were not required to have impoundments. Impoundments near the edge of the basin may have little value for surface water storage for the basin; these impoundments are near the headwaters and do not interact large with the regional surface water drainage network. It is not currently known how many impoundments have berms designed for water retention and could be considered for supplemental storage of irrigation water or large term detention of storm water runoff.

Predevelopment Hydrography

The predevelopment hydrography was developed to provide a basis for understanding basin rainfall-runoff behavior prior to the development of drainage and irrigation projects. The predevelopment hydrography was developed from 1-foot topographic data from the early 1930s (USWD, 1932). This topographic data covers a majority of the basin. These topographic maps showed the predevelopment the flowpaths for many streams and sloughs. These flowpaths were digitized from the paper copies of the maps using the current STR coverage as reference points. The result is an approximate location of each tributary, accurate to within approximately 200 feet of the actual flowpath location. This coverage provides the location of the major tributaries prior to development of the drainage projects (**Figure J-21**). When compared to the current hydrography, the predevelopment hydrography shows the changes in the drainage patterns that occurred from 1946 to 1980.
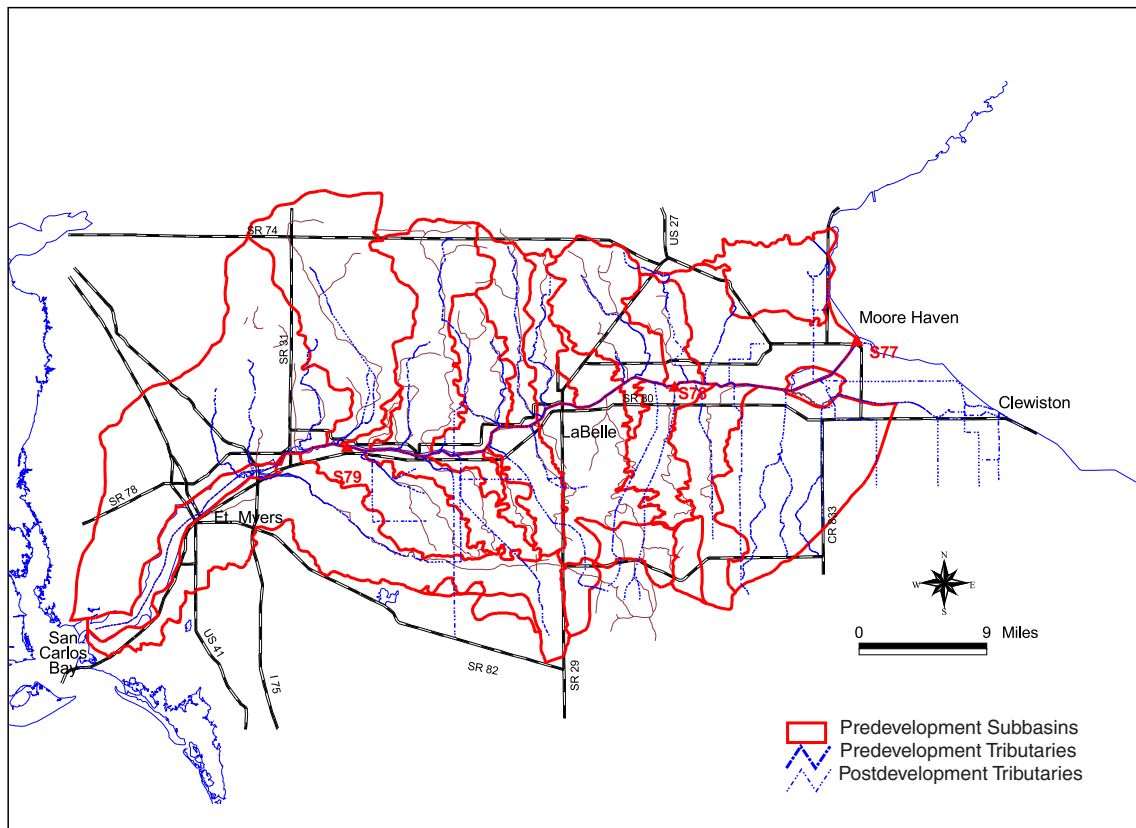
Figure J-21. Predevelopment Tributaries in the Caloosahatchee Basin.

IRRIGATION NETWORK

Water Use Permits for the Caloosahatchee River Water

Water from the Caloosahatchee River is used to supply agricultural and urban users. The region of the basin serviced by the Caloosahatchee River is known as the Lake Okeechobee Service Area (LOSA), because most of the water consumed from the Caloosahatchee River is released from Lake Okeechobee. The urban water supplies use a combination of surface and ground water sources. The Caloosahatchee River is used by LaBelle, Fort Myers and the Lee County Water Supply Authority while Cape Coral and Lehigh use ground water. The total urban use of Caloosahatchee River is approximately 7 MGD. Although the urban water use is a small fraction of total Caloosahatchee River flow during normal conditions, it is a significant fraction of river flow during droughts and, as such, is an important component of the water use network.

Agricultural land occupies a substantial portion of the LOSA (**Figure J-22**). A large percent of this land can receive supplemental irrigation water from the Caloosahatchee River (**Figure J-23**). The agricultural lands permitted to use water from the Caloosahatchee River are described in **Table J-1**. The table describes the crop, soil, project area, and irrigated area as well as the annual monthly allocations. Where appropriate the maximum daily withdrawal is listed. The daily allocation is provided for freeze protection.

The LOSA covers 425,000 acres in the eastern end of the basin (**Figure J-22**). Agricultural water use permits cover approximately 300,000 acres or 70 percent of the service area. Approximately, 170,000 acres of agricultural land are permitted to obtain irrigation water from the Caloosahatchee River. Caloosahatchee River water is used to irrigate 150,000 acres of sugarcane, citrus, vegetables, and pasture (**Table J-1**). The remaining land consists of wetlands and retention areas.
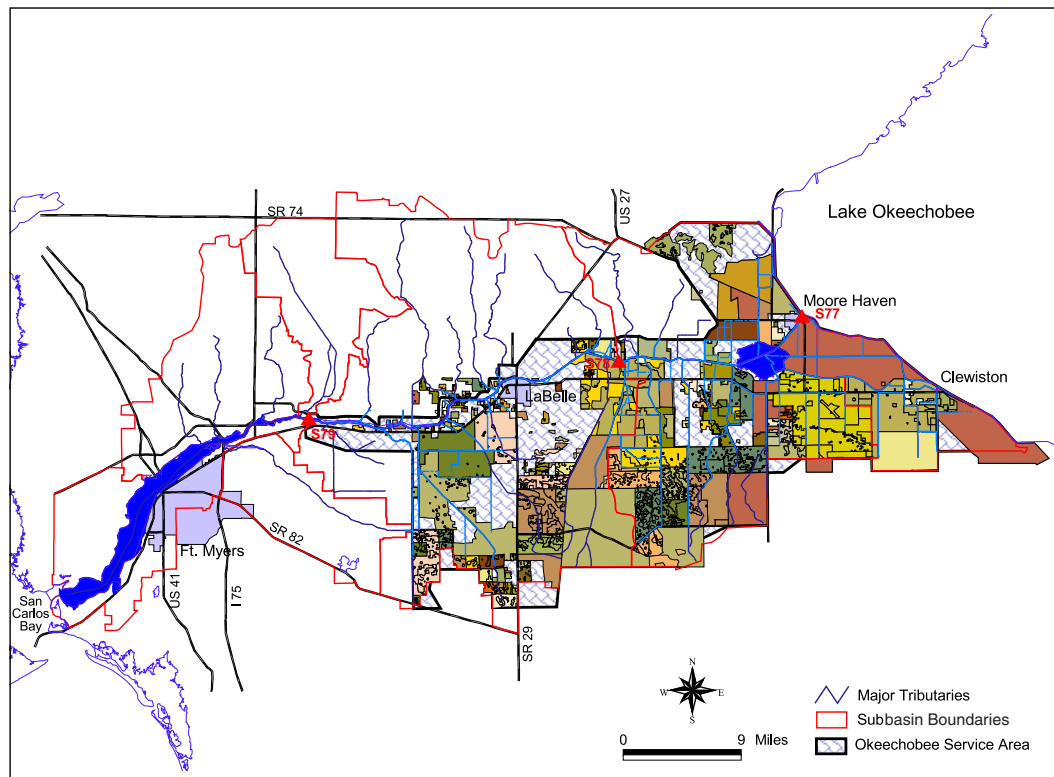
Figure J-22. Water Use Permits in the Lake Okeechobee Service Area of the Caloosahatchee Basin.
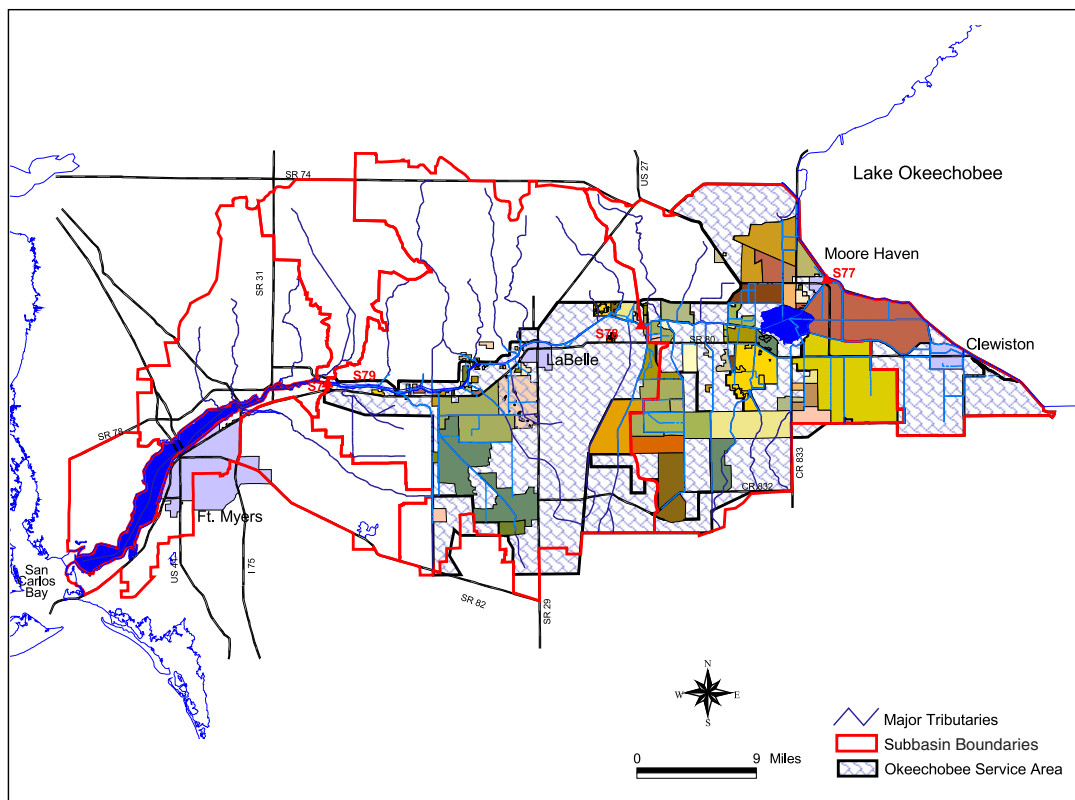
Figure J-23. Land Irrigated with Caloosahatchee River Water in the Lake Okeechobee Service Area.

Table J-1. Water Use Allocation, Crop Type, Soil Type, and Irrigated Area for Water Use Permits for Use of Caloosahatchee River Water.

Permit	Land Use	Crop Type	Soil Moisture	Rain Station	Irrigation Area	Efficiency	Annual	Monthly	Daily	Project Area (acres)
2200023W	AGR	20	1.5	19	335	0.5	267	---	-	761
2200024W	AGR	10	.8	14	1,600	0.4	3,117	413		1,870
2200029W	AGR	10	.8	14	1,100	0.5	1,496	228		1,100
2200041W	AGR	10	.8	14	5,960	0.4	11,610	1,539		6,345
2200057W	AGR	13	1.5	19	938	0.5	733	270		938
2200062W	AGR	10	.8	14	1,800	0.4	9,171	1,215		5,500
2200062W	AGR	10	.8	14	2,650	0.4	9,171	1,215		5,500
2200062W	AGR	10	1.5	14	294	0.4	9,171	1,215		5,500
2200063W	DIV	--	--	--	--	---	13,277	2,455		18,407
2200131W	AGR	13	1.5	14	1,315	0.85	605	222		1,585
2200135W	AGR	10	.8	14	927	0.5	1,261	192		1,157
2200148W	AGR	13	.8	19	302	0.85	139	51		461
2200189W	AGR	10	.8	14	927	0.35	4,236	1,171		5,993
2200189W	AGR	13	.8	19	1,274	0.6	4,236	1,171		5,993
2200189W	AGR	13	.8	19	150	0.6	4,236	1,171		5,993
2200189W	AGR	13	.8	19	1,614	0.6	4,236	1,171		5,993
2200189W	AGR	13	.8	19	699	0.6	4,236	1,171		5,993
2200189W	DIV	--	--	--	---	---	4,236	1,171		5,993
2200212W	AGR	10	.8	14	365	0.5	0	0		460
2200221W	AGR	56	.8	19	273	0.5	81	36		273
2200222W	AGR	10	1.5	14	1,032	0.5	1,154	183		1,247
2200235W	AGR	13	1.5	19	207	0.85	95	35		294
2200243W	AGR	20	1.5	14	1,308	0.5	1,167	232		1,000
2200243W	AGR	56	1.5	14	200	0.5	1,167	232		1,000
2200248W	AGR	10	.8	14	194	0.5	333	43		273
2200248W	AGR	15	.8	14	50	0.5	333	43		273
2200280W	AGR	60	.8	19	193	0.5	1,720	306		1,872
2200280W	AGR	60	.8	19	333	0.5	1,720	306		1,872
2200280W	AGR	60	.8	19	539	0.5	1,720	306		1,872
2600022W	AGR	13	1.5	19	168	0.85	77	948		187
2600024W	IND	--	--	--	--	--	1,564	0	7.46	54,200
2600024W	PWS	0	--	68	17	--	"	0	7.46	54,200
2600026W	AGR	13	.8	14	1,274	0.85	586	215		1,727
2600030W	AGR	13	.8	19	31	0.85	201	43.7		265
2600030W	AGR	13	.8	19	50	0.85	201	43.7		265
2600030W	AGR	13	.8	19	105	0.85	201	43.7		265
2600030W	AGR	13	.8	19	40	0.85	201	43.7		265
2600062W	AGR	13	1.5	19	40	0.85	18.4	6.77		40

Land Use: AGR - agricultural; IND - industrial; LAN - landscaping; NUR - nursery;
PWS - Public Water Supply.
Crop Type: 10 - sugarcane; 13 - citrus; 15 - sod; 20 - pasture; 25 - palm trees; 56 - melons;
60 - tomatoes.

Table J-1. Water Use Allocation, Crop Type, Soil Type, and Irrigated Area for Water Use Permits for Use of Caloosahatchee River Water.

Permit	Land Use	Crop Type	Soil Moisture	Rain Station	Irrigation Area	Irrigation Efficiency	Annual	Monthly	Daily	Project Area (acres)
2600063W	AGR	13	1.5	19	40	0.75	20.8		.256	40
2600076W	AGR	13	1.5	19	395	0.75	206		2.53	460
2600077W	AGR	10	.8	14	18	0.5	340	56		480
2600077W	AGR	20	.8	14	300	0.5	340	56		480
2600082W	AGR	13	.8	19	600	0.35	11,680	143		18,000
2600082W	AGR	13	.8	19	11,764	0.6	11,680	143		18,000
2600082W	AGR	13	.8	19	4,535	0.53	11,680	143		18,000
2600092W	AGR	13	1.5	19	5	0.75	2.61		.032	5
2600093W	AGR	13	.4	19	17	0.75	8.86		.109	17
2600095W	AGR	13	1.5	19	26	0.5	36.3		.361	46
2600095W	AGR	20	1.5	19	20	0.5	36.3		.361	46
2600106W	AGR	13	.8	19	12,000	0.5	22,948	6,167		29,040
2600108W	AGR	15	.8	19	1,335	0 4	11,205	1,545		107,400
2600108W	AGR	60	.8	19	3,300	0.4	11,205	1,545		107,400
2600108W	AGR	20	.8	19	12,800	0.5	11,205	1,545		107,400
2600122W	AGR	13	.8	19	181	0.75	94.4	34.7		210
2600123W	AGR	13	.8	19	618	0.5	796	293		1,386
2600123W	AGR	13	.8	19	680	0.85	796	293		1,386
2600139W	AGR	10	.8	15	11,894	0.5	29,010	4,847		23,807
2600139W	AGR	13	.8	15	3,194	0.5	29,010	4,847		23,807
2600139W	LAN	15	.8	15	480	0.5	29,010	4,847		23,807
2600139W	AGR	20	.8	15	6,965	0.5	29,010	4,847		23,807
2600147W	LAN	15	.8	19	31	0.75	34.7		.1152	43
2600158W	AGR	13	.8	19	314	0.85	144		1.77	338
2600161W	AGR	13	.8	19	500	0.85	445	84.6		640
2600173W	AGR	13	.8	19	4,338	0.85	1,995	734		5,188
2600176W	AGR	15	.8	19	1,335	0.4	19,904	4,892		62,745
2600176W	AGR	13	1.5	19	640	0.5	19,904	4,892		62,745
2600176W	AGR	13	.8	19	5,535	0.5	19,904	4,892		62,745
2600176W	AGR	13	.8	19	4,338	0.85	19,904	4,892		62,745
2600176W	AGR	13	.8	19	2,640	0.85	19,904	4,892		62,745
2600176W	AGR	13	.8	19	1,179	0.85	19,904	4,892		62,745
2600176W	AGR	10	.8	19	2,663	0.5	19,904	4,892		62,745
2600176W	AGR	10	.8	19	2,127	0.5	19,904	4,892		62,745
2600176W	AGR	10	.8	19	1,072	0.5	19,904	4,892		62,745
2600176W	AGR	60	.8	19	1,107	0.5	19,904	4,892		62,745
2600177W	AGR	13	.8	19	2,640	0.85	1,214	447		3,280
2600179W	AGR	13	.8	19	5,535	0.5	4,828	1,777		6,500

Land Use: AGR - agricultural; IND - industrial; LAN - landscaping; NUR - nursery;
PWS - Public Water Supply.
Crop Type: 10 - sugarcane; 13 - citrus; 15 - sod; 20 - pasture; 25 - palm trees; 56 - melons;
60 - tomatoes.

Table J-1. Water Use Allocation, Crop Type, Soil Type, and Irrigated Area for Water Use Permits for Use of Caloosahatchee River Water.

Permit	Land Use	Crop Type	Soil Moisture	Rain Station	Irrigation Area	Irrigation Efficiency	Water Allocation (acre-feet) Annual	Water Allocation (acre-feet) Monthly	Water Allocation (acre-feet) Daily	Project Area (acres)
2600179W	AGR	13	1.5	19	640	0.5	4,828	1,777		6,500
2600215W	AGR	13	.8	19	199	0.85	91.3		1.12	260
2600222W	AGR	13	.8	19	1,018	0.85	905	197		1,205
2600234W	AGR	13	.8	15	613	0.85	282	104		669
2600235W	AGR	13	.8	19	1,614	0.85	742	273		2,088
2600236W	AGR	13	.8	19	30	0.85	13.8		.169	37
2600246W	AGR	13	1.5	19	52	0.85	24.2		.296	55
2600250W	AGR	10	.8	15	300	0.5	448	64.8		341
2600259W	AGR	13	.8		150	0.85	69	25.4		204
2600260W	AGR	13	1.5	19	23	0.85	10.6		.13	24
2600264W	AGR	13	.8	19	31	0.85	14.2		.175	35
2600279W	AGR	13			1,179	0.85	542	200		1,442
2600286W	AGR	13	.8	19	57	0.85	51.	11.1		73
2600292W	AGR	10	.8	14	1,048	0.5	1,425	217.		1,499
2600293W	AGR	13	.8	14	78	0.85	164	36.7		225
2600293W	AGR	20	.8	19	127	0.5	164	36.7		225
2600298W	AGR	13	.8	19	161	0.85	74.1		.909	165
2600306W	AGR	13	.8	19	2,776	0.85	1,599	529		7,680
2600306W	AGR	20	.8	19	320	0.5	1,599	529		7,680
2600315W	AGR	10	.8	19	1,072	0.5	1,420	209		3,476
2600316W	AGR	13	.8	19	85	0.85	39		.48	72
2600326W	AGR	13	1.5	19	47	0.85	21.6		.265	47
2600350W	AGR	13	1.5	19	13	0.85	6		.0734	14.6
2600356W	PWS		1.25	50	--	0.80	1,999	14.6	.05	106
2600357W	LAN	15	1.5	19	5	0.85	73.3		.4	106
2600357W	LAN	15	1.5	19	60	0.75	73.3		.4	106
2600357W	LAN	15	1.5	19	15	0.85	73.3		.4	106
2600376W	AGR	13	.8	19	260	0.85	231	50		258
2600377W	AGR	10	.8	14	1,673	0.5	2,275	347		2,138
2600378W	AGR	13	--	--	12	---	--		.0057	12
2600380W	AGR	13	1.5	19	15	0.85	7.0		.086	42.5
2600405W	AGR	13	1.5	19	11	0.85	5.1		.062	11
2600406W	AGR	13	1.5	19	24	0.85	14.4		.133	25.5
2600417W	AGR	13	.8	19	699	0.85	322	118		81
2600421W	AGR	13	1.5	19	289	0.85	133		1.63	304
2600422W	AGR	13	1.5	19	110	0.85	50.6		.621	117
2600451W	AGR	13	.8	14	141	0.85	65	23.9		20
2600459W	AGR	13	.8	19	32	0.85	14.5		.18	38

Land Use: AGR - agricultural; IND - industrial; LAN - landscaping; NUR - nursery;
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60 - tomatoes.

Table J-1. Water Use Allocation, Crop Type, Soil Type, and Irrigated Area for Water Use Permits for Use of Caloosahatchee River Water.

Permit	Land Use	Crop Type	Soil Moisture	Rain Station	Irrigation Area	Irrigation Efficiency	Annual	Monthly	Daily	Project Area (acres)
2600463W	AGR	56	.8	19	464	0.5	138	60.7		600
2600465W	AGR	13	1.5	19	11	0.85	5.1		.06	13
2600467W	AGR	13	.8	14	157	0.6	257	94.7		1,328
2600467W	AGR	13	.8	14	238	0.6	257	94.7		1,328
2600475W	AGR	13	.8	19	112	0.85	51.5	19		126
2600495W	AGR	10	.8	19	1,680	0.5	8,349	1,386		2,308
2600495W	AGR	13	.8	19	832	0.85	8,349	1,386		2,308
2600495W	AGR	20	.8	19	783	0.5	8,349	1,386		2,308
2600495W	AGR	13	.8	19	402	0.85	8,349	1,386		2,308
2600495W	AGR	10	.8	19	1,762	0.5	8,349	1,386		2,308
2600495W	AGR	10	.8	19	1,816	0.5	8,349	1,386		2,308
2600510W	AGR	60	.8	19	342	0.5	18,878	3,272		15,285
2600510W	AGR	60	.8	19	402	0.5	18,878	3,272		15,285
2600510W	AGR	13	.8	19	750	0.85	18,878	3,272		15,285
2600510W	AGR	13	.8	19	240	0.85	18,878	3,272		15,285
2600510W	AGR	60	.8	19	262	0.5	18,878	3,272		15,285
2600510W	AGR	60	.8	19	239	0.5	18,878	3,272		15,285
2600510W	AGR	20	.8	19	1,554	0.5	18,878	3,272		15,285
2600510W	AGR	20	.8	19	1,026	0.5	18,878	3,272		15,285
2600510W	AGR	20	.8	19	759	0.5	18,878	3,272		15,285
2600510W	AGR	20	.8	19	654	0.5	18,878	3,272		15,285
2600510W	AGR	20	.8	19	497	0.5	18,878	3,272		15,285
2600510W	AGR	20	.8	19	289	0.5	18,878	3,272		15,285
2600510W	AGR	60	.8	19	293	0.5	18,878	3,272		15,285
2600510W	AGR	13	.8	19	1,096	0.85	18,878	3,272		15,285
2600510W	AGR	60	.8	19	777	0.5	18,878	3,272		15,285
2600510W	AGR	60	.8	19	798	0.5	18,878	3,272		15,285
2600510W	AGR	60	.8	19	1,190	0.5	18,878	3,272		15,285
2600510W	AGR	60	.8	19	1,041	0.5	18,878	3,272		15,285
2600510W	AGR	60	.8	19	809	0.5	18,878	3,272		15,285
2600537W	AGR	13	.8	19	40	0.85	24.2	5.13		30.5
2600543W	AGR	13	1.5	19	3.5	0.8			.02	4.6
2600603W	AGR	13	.8	19	240	0.85	1,855	402		2,156
2600603W	AGR	13	.8	19	750	0.85	1,855	402		2,156
2600603W	AGR	13	.8	19	1,095	0.85	1,855	402		2,156
3600003W	PWS	--	1.4	---	115	- --	4,882		8.7	34,000
3600004W	NUR	5	1.5	19	36	0.5	51		.28	83
3600006W	AGR	13	1.5	19	161	0.75	84		1.03	167

Land Use: AGR - agricultural; IND - industrial; LAN - landscaping; NUR - nursery;
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Table J-1. Water Use Allocation, Crop Type, Soil Type, and Irrigated Area for Water Use Permits for Use of Caloosahatchee River Water.

Permit	Land Use	Crop Type	Soil Moisture	Rain Station	Irrigation Area	Irrigation Efficiency	Annual	Monthly	Daily	Project Area (acres)
3600023W	AGR	13	1.5	20	20	0.85	9.2		.113	20
3600024W	AGR	13	.8	19	190	0.85	170	36.8		675
3600035W	PWS	--	1.4	157	57	----	3,255	12.5		1
3600262W	AGR	13	1.5	19	65	0.85	30		.367	70
3600829W	AGR	13	.8	19	240	0.85	110		1.35	260
3601134W	AGR	13	.8	19	12	0.85	11.8		.063	13
3601882W	AGR	13	1.5						.02	1.5
3602064W	AGR	25	---	--	8	---	---	---	.02	11
3602869W	LAN	15	1.5	2	8	0.8	.02		.02	8
3602874W	AGR	5	.8	2	94	0.85	106		14.5	94
3602877W	AGR	5	.8	2	47	0.85	53.1		7.24	55
3603179W	LAN	15	.8	2	14	0.8	35.1		.263	34.8
3603179W	LAN	--	--	--	--	---	35.1		.263	34.8
3603179W	PWS	--	2.73	137	104	0.4	35.1		.263	34.8

Land Use: AGR - agricultural; IND - industrial; LAN - landscaping; NUR - nursery;
PWS - Public Water Supply.
Crop Type: 10 - sugarcane; 13 - citrus; 15 - sod; 20 - pasture; 25 - palm trees; 56 - melons;
60 - tomatoes.

Permitted Surface Water Pumps

Surface water pumps are an important component of the irrigation network. The network is the system of canals that supplies water for the irrigation pumps. The irrigation strategy in the basin has been to maintain the water levels in the irrigation supply canals for the growers to withdrawal water as needed. Location and characteristics of the surface water pumps is necessary information for constructing and simulating irrigation in the basin. A coverage was created that includes pumps used for water supply purposes. The coverage was created from the list of pumps was developed from the water use permit files obtained from the Water Use Division of SFWMD (**Figure J-24**). The pump list included pumps that tapped both ground water and surface water. Water supply pumps draw water from the six aquifers as well as surface water sources. The surface water sources include on-site ponds and canals and the water table aquifer which are closely connected. Most of the supplemental irrigation water used in the LOSA not obtained from the Caloosahatchee River is obtained from either the Sandstone aquifer, Surficial Aquifer System (SAS), or the lower Tamiami aquifer. A few farms obtain irrigation water from the water table aquifer or on-site surface sources. Water obtained from the latter sources could be essentially using Caloosahatchee River water that had pumped into the irrigation canals and seeped back into the water table aquifer. As a result, surface water irrigation network only included the pumps for surface water from the Caloosahatchee River.

The surface water pumps in the irrigation network were those associated with water use permits that were allocated water from the Caloosahatchee River and those pumps whose attributes indicated that the water source was the C-43 Canal. The characteristics of the pumps using river water are provided in **Table J-2**. The characteristics include the permit number for reference, type of pump, pump location in State Planar coordinates (Florida East Zone), intake elevation, pump size and capacity (where information is available), and the source canal of the irrigation network.

The pump locations were checked for accuracy by the Water Use Division staff and checked again by IFAS staff to ensure that the pumps were located on the correct permit. However, where the grower may have recently moved pumps the locations may be inaccurate. The irrigation pumps listed in this report consist of the primary farm pumps. Supplemental pumps or temporary pumps are not listed. It has been common practice to move or add additional pumps to meet local irrigation requirements within the permitted allocation. Additional pumps within the permitted parcel are not listed in the database and included in the coverage. The information on the pumps could not be verified.

Irrigation Network

The irrigation network for the Caloosahatchee Basin is the combination of pumps and canals that deliver water from the river to the user. The irrigation network includes the Caloosahatchee River and several secondary canals, which are used to deliver water from the river to the individual farm. The secondary canals are controlled and maintained by water control districts (WCDs) that are in turn owned by landowners within each district. Many of the WCDs are special taxing districts (Chapter 298 F.S.) while a few of the
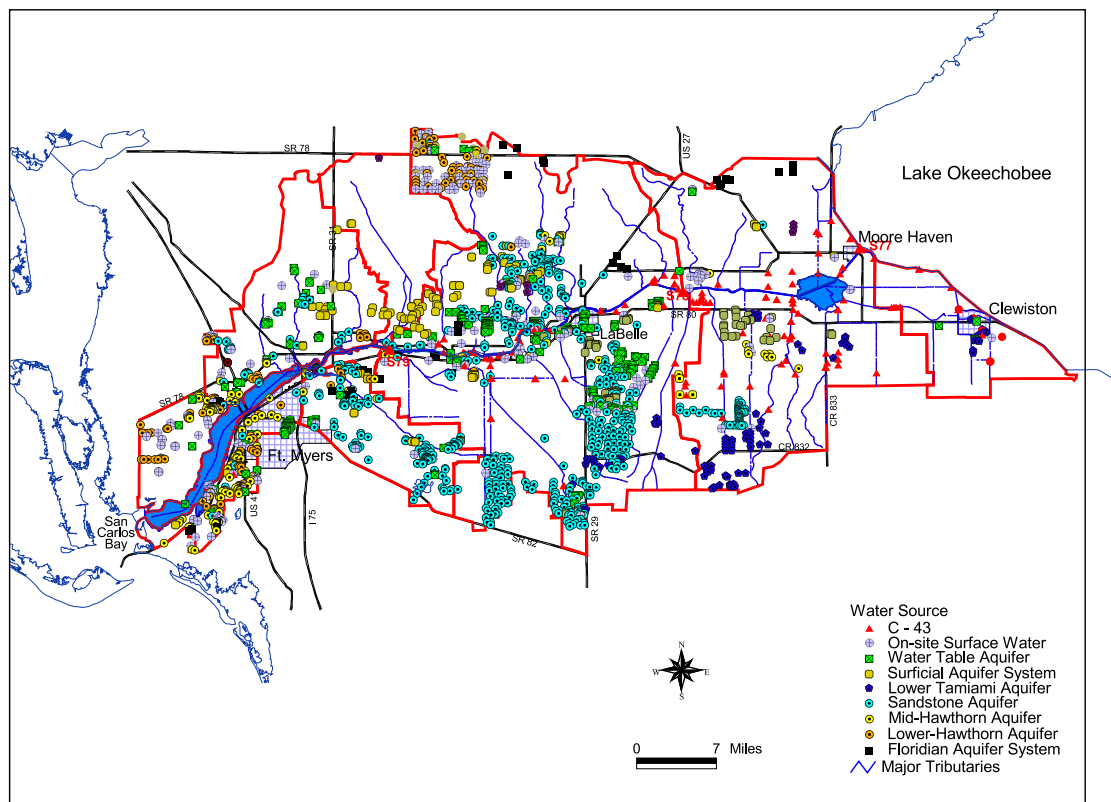
Figure J-24. Permitted Surface and Ground Water Pumps in the Caloosahatchee Basin.

Table J-2. Surface Water Pump Information for Caloosahatchee Surface Water Usage.

Number	Water Use Permit	Pump	Location (State Planar)		Intake Elevation (NGVD)	Pump Properties				Water Source
			Easting	Northing		Diameter (in.)	Stat	Type	Capacity (GPM)	
1	2200002W	1	453798	917324	7.5	24	01		16,000	C-19
2	2200006W	1	373860	886759	3	8	01	PORTA	2,500	C-43
3	2200006W	2	370117	884165	3	8	01	PORTA	2,500	C-43
4	2200023W	1	385233	896338	-3.8	18	01	TURBI	6,000	C-43/ CYPRESS BRANCH
5	2200024W	1	459958	921918	5	24	01	DIESE	14,000	L-41
6	2200024W	2	467909	914365	5	24	02	DIESE	14,000	C-43
7	2200029W	1	454702	908275		36	01		25,000	C-19
8	2200029W	2	454649	899912		32	01		30,000	C-19
9	2200041W	1	454331	918335	4.5	24	02	AXIAL	13,000	C-19
10	2200041W	2	454626	927711	5	18	01	AXIAL	6,000	L-42
11	2200041W	3	454627	927020	7.5	18	01	AXIAL	6,000	L-42
12	2200041W	4	459462	927119	3	23	01	AXIAL	10,000	L-41
13	2200041W	5	453936	932941	7	24	01	AXIAL	13,000	C-19
14	2200057W	1	394394	895460		18	01		6,000	C-43
15	2200057W	2	394568	895456		16	01		6,000	C-43
16	2200057W	3	394398	898908		16	01		3,500	C-43 CANAL
17	2200057W	4	394650	898891		14	01		4,200	C-43 CANAL
18	2200061W	1	454841	916384		36	01	AXIAL	30,000	C-19 CANAL
19	2200062W	1	443709	900683	5	36	01	AXIAL	25,000	C-43 CANAL
20	2200062W	2	454270	908421	5	48	02	AXIAL	50,000	C-19 CANAL
21	2200063W	1	467020	894174	4	60	01	VERT	80,000	LAKE HICPOCHEE
22	2200063W	2	496710	901579	4	52	01	CENTR	70,000	LD-1
23	2200063W	3	510205	893975	4	36	01	VERT	30,000	LD-1
24	2200063W	4	510205	893975	4	36	01	VERT	30,000	LD-1
25	2200063W	5	510205	893975	4	36	01	VERT	30,000	LD-1
26	2200063W	6	496710	901579	4	52	01	CENTR	70,000	LD-1
27	2200063W	7	478117	906094	9	52	01	CENTR	56,000	LD-3
28	2200063W	8	478117	906094	6	30	01	VERT	18,000	LD-3
29	2200063W	9	478117	906094	9	52	01	CENTR	56,000	LD-3
30	2200131W	1	437195	888908	6.5	12	02	AXIAL	3,000	C-43
31	2200131W	2	437195	888908	6.5	12	02	AXIAL	2,500	C-43
32	2200131W	3	437454	891293		24	02	CENTR	8,000	C-43
33	2200131W	4	437435	891293		24	02	CENTR	8,000	C-43
34	2200135W	1	443962	887397		12	02	AXIAL	3,000	C-43
35	2200135W	2	444037	884664		10	02	AXIAL	2,000	C-43
36	2200135W	3	446144	883248		24	02	AXIAL	12,000	C-43
37	2200148W	1	390046	898989		8	02	AXIAL	1,500	C-43/ CYPRESS BRANCH
38	2200148W	2	386212	897575		3	02	CENTR	200	C-43/ CYPRESS BRANCH
39	2200148W	3	386284	896031		18	02	AXIAL	7,500	C-43/ CYPRESS BRANCH
40	2200189W	1	443785	888994	-4	48	02	AXIAL	50,000	C-43/ HILLIARD CANAL
41	2200189W	2	443785	888962	-4	48	02	AXIAL	50,000	C-43/ HILLIARD CANAL
42	2200189W	3	443785	888932	-4	48	02	AXIAL	50,000	C-43/ HILLIARD CANAL

Table J-2. Surface Water Pump Information for Caloosahatchee Surface Water Usage.

Number	Water Use Permit	Pump	Location (State Planar) Easting	Northing	Intake Elevation (NGVD)	Pump Properties Diameter (in.)	Stat	Type	Capacity (GPM)	Water Source
43	2200212W	1	464949	902389	7	36	01		20,000	C-43/ NEWHALL
44	2200221W	1	390044	886378	10.5	10	01	CENTR	1,500	C-43
45	2200222W	1	443875	895500	6	16	01	AXIAL	4,000	C-43/ UNNAMED
46	2200222W	2	433625	900100	6	16	02	AXIAL	4,000	C-43/ UNNAMED
47	2200222W	3	433625	894400	6	18	02	AXIAL	5,000	C-43/ UNNAMED
48	2200235W	1	396035	893416	0		02	CENTR	8,500	C-43
49	2200243W	1	412642	895362	6	24	01	AXIAL	14,000	C-43 UNNAMED
50	2200248W	1	463744	899608	8	12	02	AXIAL	2,500	C-43
51	2200280W	1	409458	887704	6	8	02	CENTR	2,000	C-43/ CANAL 3
52	2200280W	2	407596	887704	6	8	02	CENTR	2,000	C-43/ CANAL 3
53	2200280W	3	405919	888664	6	8	02	CENTR	2,000	C-43/ CANAL 3
54	2200280W	4	405925	890184	6	8	02	CENTR	2,000	C-43/ CANAL 3
55	2200280W	5	405979	891705	6	8	02	CENTR	2,000	C-43/ CANAL 3
56	2200280W	6	405101	888121	6	8	02	CENTR	2,500	C-43/ CANAL 3
57	2200280W	7	403695	887658	6	8	02	CENTR	2,500	C-43/ CANAL 3
58	2200280W	8	402119	888088	6	8	02	CENTR	2,500	C-43/ CANAL 3
59	2600003W	1	457687	880386	9	60	02	AXIAL	100,000	C-43/ HILLIARD CANAL
60	2600003W	2	457687	880386	9	60	02	AXIAL	100,000	C-43/ HILLIARD CANAL
61	2600022W	1	335362	865023		16	01	AXIAL	10,000	BANANA BRANCH
62	2600022W	2	332776	864005		8	01	AXIAL	2,500	FORT SIMMONS BRANCH
63	2600024W	1	539048	891156	5.31	14	01	CENTR	2,100	LAKE OKEECHOBEE
64	2600024W	2	539048	891156	5.31	14	01	CENTR	2,100	LAKE OKEECHOBEE
65	2600024W	3	539048	891156	5.31	14	01	CENTR	2,400	LAKE OKEECHOBEE
66	2600024W	4	539048	891156	5.31	14	01	CENTR	5,600	LAKE OKEECHOBEE
67	2600024W	5	531569	880029	6	12	02	CENTR	5,000	LAKE OKEECHOBEE
68	2600024W	6	523209	874069	8	16	02	MIX F	5,000	LAT. CANAL 16
69	2600026W	1	443280	879815	11	24	01	AXIAL	15,000	C-43/ HILLIARD C
70	2600026W	2	443280	879700	11	18	01	AXIAL	6,000	C-43/ HILLIARD C
71	2600030W	1	330290	878950	11	6	01	CENTR	1,200	JACKS BRANCH
72	2600030W	2	329297	879417	10.6	4	01	CENTR	500	JACKS BRANCH
73	2600031W	1	339718	875742	7	6	01	CENTR	900	C-43
74	2600031W	2	339780	875760	10	8	01	TURBI	1,300	C-43
75	2600046W	1	346600	881700		6	01	CENTR	500	C-43/ BEE BRANCH
76	2600058W	1	345959	874679		12	01		3,200	C-43
77	2600062W	1	342265	875926	9	4	01	CENTR	30	C-43
78	2600063W	1	342412	876234		6	01		1,500	C-43
79	2600076W	1	320824	865332		8	01	CENTR	1,400	C-43/ TOWNSEND CANAL
80	2600076W	2	317741	864452		12	01	TURBI	2,000	C-43/ TOWNSEND CANAL
81	2600076W	3	317375	864059		6	01	CENTR	1,200	C-43/ TOWNSEND CANAL
82	2600076W	4	315536	864454		8	01	CENTR	1,200	C-43/ TOWNSEND CANAL
83	2600076W	5	317405	861288		6	01	CENTR	1,200	C-43/ TOWNSEND CANAL
84	2600082W	1	317858	856004		36	01		40,000	C-43/ TOWNSEND CANAL

Table J-2. Surface Water Pump Information for Caloosahatchee Surface Water Usage.

Number	Water Use Permit	Pump	Location (State Planar) Easting	Northing	Intake Elevation (NGVD)	Diameter (in.)	Stat	Type	Capacity (GPM)	Water Source
85	2600082W	2	317858	856004		36	01		40,000	C-43/ TOWNSEND CANAL
86	2600082W	3	336189	855890		20	01		11,000	C-43/ TOWNSEND CANAL
87	2600082W	4	336189	855890		20	01		11,000	C-43/ TOWNSEND CANAL
88	2600082W	5	336189	855890		20	01		11,000	C-43/ TOWNSEND CANAL
89	2600082W	6	348734	855863		36	01		40,000	C-43/ TOWNSEND CANAL
90	2600092W	1	333865	876296		6	01	CENTR	800	C-43
91	2600093W	1	335870	876127		6	01	CENTR	800	JACKS BRANCH
92	2600093W	1	335870	876127		6	01		750	C-43
93	2600095W	1	332350	877500		6	01	CENTR	800	JACKS BRANCH
94	2600106W	1	317793	849042			01			C-43/ TOWNSEND CANAL
95	2600106W	2	317831	849077			01			C-43/ TOWNSEND CANAL
96	2600106W	3	317903	850366	10	36	01	AXIAL	28,000	C-43
97	2600106W	4	317903	850366	10	36	02	AXIAL	28,000	C-43
98	2600108W	1	408533	819863	0	16	01	AXIAL	2,500	DGWCD E-3 CANAL
99	2600108W	2	409924	821283	0	30	02	AXIAL	10,000	DGWCD E-3 CANAL
100	2600122W	1	317646	839228	25	18	01	PROPE	5,300	C-43/ HENDRY C
101	2600122W	2	317657	839180	25	8	01	TURBI	700	C-43/ HENDRY C
102	2600123W	1	414752	882056	8	30	01	AXIAL	25,000	C-43
103	2600123W	2	419232	884575	15	28	02	AXIAL	20,000	C-43
104	2600139W	1	462844	884703		48	01			C-43
105	2600139W	2	462844	884703		48	01			C-43
106	2600139W	3	462844	884703		42	01			C-43
107	2600139W	4	478973	858268			01		15,000	C-43
108	2600139W	5	485251	885560			01		5,000	C-43
109	2600139W	6	465265	888720			01		6,000	C-43
110	2600139W	7	488811	885891			01		4,000	C-43
111	2600139W	8	487227	885785			01		5,000	C-43
112	2600139W	9	486357	885717			01		6,000	C-43
113	2600147W	1	363664	884203		10	01		80	C-43
114	2600158W	2	353000	873000	10	8	01	CENTR	4,000	MESSER CANAL
115	2600158W	1	352000	873750	10	8	01	CENTR	4,000	MESSER CANAL
116	2600161W	1	315542	816392	23	8	02	CENTR	800	LEHIGH CANAL
117	2600173W	1	399000	852750	0	0	02	AXIAL	7,000	C-43/ CANAL 3
118	2600173W	2	414000	852750	0	0	02	AXIAL	14,000	C-43/ CANAL 3
119	2600173W	3	426000	852750	0	0	02	AXIAL	13,000	C-43/ CANAL 3
120	2600176W	1	414400	857653		54	01	AXIAL	75,000	C-43/ CANAL 3
121	2600176W	2	414400	857653		54	01	AXIAL	75,000	C-43/ CANAL 3
122	2600176W	3	415000	865229	2.5	54	02	AXIAL	75,000	C-43/ CANAL 3
123	2600176W	4	415010	865229	2.5	54	02	AXIAL	75,000	C-43/ CANAL 3
124	2600177W	1	414507	839577	20	36	02		28,000	C-43/ CANAL 3
125	2600179W	1	394700	862400	18.5	30	01	AXIAL	15,000	C-43/ CANAL 3
126	2600179W	2	394700	862400	18.5	30	01	AXIAL	15,000	C-43/ CANAL 3

Table J-2. Surface Water Pump Information for Caloosahatchee Surface Water Usage.

Number	Water Use Permit	Pump	Location (State Planar) Easting	Northing	Intake Elevation (NGVD)	Diameter (in.)	Stat	Type	Capacity (GPM)	Water Source
127	2600215W	2	338071	877846	-3	12	02	TURBI	1,140	C-43
128	2600222W	4	348009	811096	22	10	02	CENTR	3,500	TOWNSEND CANAL
129	2600222W	2	348377	810920	22	10	01	CENTR	3,500	TOWNSEND CANAL
130	2600234W	1	457753	860627	14.5	8	02		1,500	C-43/ H-H CANAL
131	2600234W	2	457753	860627	14.5	8	02		1,500	C-43/ H-H CANAL
132	2600234W	3	457753	860627	14.5	54	02		40,000	C-43/ H-H CANAL
133	2600235W	1	439100	862000	11	30	01	AXIAL	15,000	MYRTLE SLOUGH C
134	2600235W	2	441000	863400	11	30	01	AXIAL	15,000	JACK SPRAT
135	2600235W	3	434550	873200	11	30	01	AXIAL	15,000	C-43/ H-H CANAL
136	2600235W	4	435340	868342	11		02	AXIAL	25,000	MYRTLE SLOUGH
137	2600235W	5	441499	869873		30	02	AXIAL	15,000	C-43/ H-H CANAL
138	2600236W	1	337375	876750		12	01	CENTR	446	C-43
139	2600246W	1	349700	883040	3	6	01	CENTR	600	C-43
140	2600246W	2	349700	883040	3	4	01	CENTR	350	C-43
141	2600250W	1	457797	866408	13	12	01	AXIAL	3,500	C-43/ H-H CANAL
142	2600259W	1	458258	862464	12	24	02	TURBI	11,500	C-43/CR-833 CANAL
143	2600260W	1	323000	866310		3	02	CENTR	175	C-43
144	2600264W	1	330500	875550	10	8	01	TURBI	750	C-43
145	2600279W	1	399229	854351	18	12	02	AXIAL	3,500	3-S LATERAL
146	2600279W	2	399397	848999	18	8	02	AXIAL	1,000	3-S LATERAL
147	2600292W	1	462970	866934	14	10	02	AXIAL	1,300	LAT 1-2
148	2600292W	2	462970	866934	14	10	02	AXIAL	1,300	LAT 1-2
149	2600292W	3	463023	863864	13	24	01	AXIAL	11,500	LAT 1-2
150	2600293W	1	423000	875000	14	8	02	AXIAL	1,600	C-43
151	2600298W	1	329700	871480	3	12	01	CENTR	650	C-43
152	2600306W	1	433761	842942	16.5	24	01	AXIAL	12,500	JACK SPRAT CANAL
153	2600315W	5	412000	824100	21	16	02	AXIAL	4,500	C-3
154	2600315W	1	415600	827600	21	8	02	AXIAL	1,000	C-3
155	2600315W	2	415600	830800	21	8	02	AXIAL	1,000	C-3
156	2600315W	4	415000	837800	21	8	02	AXIAL	1,200	C-3
157	2600315W	3	415000	834300	21	8	02	AXIAL	1,000	C-3
158	2600316W	1	349577	875190	10.5	10	01	CENTR	1,000	MESSER CANAL
159	2600326W	1	327171	880235	3	3	01	CENTR		JACKS BRANCH
160	2600326W	2	327171	880235	3	4	02	TURBI	300	JACKS BRANCH
161	2600350W	1	331424	875883	0	4	02	CENTR	300	C-43
162	2600352W	1	331533	878022	5	2	01		130	JACKS BRANCH
163	2600356W	1	326664	866972			02	CENTR	50	C-43
164	2600357W	1	264426	813423			01	CENTR	200	C-43
165	2600361W	1	346562	873098	5.2	10	02	TURBI	2,500	ADJACENT CANAL
166	2600376W	1	426732	880093	13	8	01	AXIAL	1,000	C-43/ 42-FOOT CANAL
167	2600377W	1	463012	861516	13	24	02	AXIAL	11,500	C-43/ H-H CANAL
168	2600378W	1	428893	892290	8		01	CENTR	350	C-43

Table J-2. Surface Water Pump Information for Caloosahatchee Surface Water Usage.

Number	Water Use Permit	Pump	Location (State Planar)		Intake Elevation (NGVD)	Pump Properties				Water Source
			Easting	Northing		Diameter (in.)	Stat	Type	Capacity (GPM)	
169	2600380W	1	327992	869154		6	02	CENTR	3,000	C-43
170	2600405W	1	332671	878656		3	01	CENTR	370	JACKS BRANCH
171	2600406W	1	330211	868104	5.3		02		320	BANANA BRANCH
172	2600417W	1	442700	872950		24	01	AXIAL	17,000	C-43/ HILLIARD CANAL
173	2600417W	2	442710	872430		24	01	AXIAL	17,000	C-43/ HILLIARD CANAL
174	2600421W	1	328900	870500	-1	12	02	TURBI	3,800	C-43
175	2600421W	2	329100	873000	-1	18	02	TURBI	7,000	C-43
176	2600422W	1	329044	866047	3	10	02	TURBI	1,200	FORT SIMMONS BRANCH
177	2600422W	2	329044	866047		12	02	CENTR	3,000	FORT SIMMONS BRANCH
178	2600451W	1	440402	873830	14	40	02	AXIAL	15,000	C-43/ H-H CANAL
179	2600459W	1	337221	876224		3	02	AXIAL	100	C-43
180	2600459W	2	335767	876233		8	02	AXIAL	600	C-43
181	2600463W	1	415206	857786	20.5	10	02	CENTR	2,000	C-43/ CANAL 3
182	2600463W	2	415133	858649	20.5	10	02	CENTR	2,000	C-43/ CANAL 3
183	2600465W	1	329250	869125		3	01	CENTR	200	BANANA BRANCH
184	2600467W	1	432665	889905	8.5	48	02	AXIAL	40,000	C-43/ MYRTLE SLOUGH
185	2600467W	2	432665	889905	8.5	48	02	AXIAL	40,000	C-43/ MYRTLE SLOUGH
186	2600467W	3	432670	881200	10	42	02	AXIAL	30,000	C-43/ MYRTLE SLOUGH
187	2600467W	4	432670	881200	10	48	02	AXIAL	40,000	C-43/ MYRTLE SLOUGH
188	2600475W	1	426600	867050		16	02	AXIAL	6,000	C-43/ 42-FOOT CANAL
189	2600495W	1	444975	857750			02	AXIAL	35,000	C-43/ HILLIARD CANAL
190	2600495W	2	443454	873790			02	AXIAL	15,000	C-43/ HILLIARD CANAL
191	2600510W	1	410190	878905			02	AXIAL	150,000	C-43/ CANAL 3
192	2600510W	2	414845	862633			02	AXIAL	105,000	C-43/ CANAL 3
193	2600537W	1	332536	876032	9	8	01	TURBI	850	C-43
194	2600543W	1	329842	871260	12	2	01	CENTR	500	C-43
195	2600603W	20	403629	881851	0	0	02	TURBI	3,000	C-43/ CANAL 3
196	2600603W	19	403629	881851	0	0	02	TURBI	3,000	C-43/ CANAL 3
197	2600603W	16	402971	876079	0	0	02	TURBI	2,250	C-43/ CANAL 3
198	2600603W	15	402971	876079	0	0	02	TURBI	2,250	C-43/ CANAL 3
199	2600603W	17	400568	876069	0	0	02	TURBI	2,500	C-43/ CANAL 3
200	2600603W	18	400568	876069	0	0	02	TURBI	2,500	C-43/ CANAL 3
201	2600603W	14	401645	875612	0	0	02	TURBI	2,000	C-43/ CANAL 3
202	2600603W	13	401645	875612	0	0	02	TURBI	2,000	C-43/ CANAL 3
203	2600603W	8	403374	870674	0	0	02	TURBI	2,000	C-43/ CANAL 3
204	2600603W	7	403374	870674	0	0	02	TURBI	2,000	C-43/ CANAL 3
205	2600603W	5	406423	870652	0	0	02	TURBI	2,500	C-43/ CANAL 3
206	2600603W	6	406423	870652	0	0	02	TURBI	2,500	C-43/ CANAL 3
207	2600603W	9	400545	870647	0	0	02	TURBI	1,875	C-43/ CANAL 3
208	2600603W	10	400545	870647	0	0	02	TURBI	1,875	C-43/ CANAL 3
209	2600603W	11	398193	870641	0	0	02	TURBI	1,875	C-43/ CANAL 3
210	2600603W	12	398193	870641	0	0	02	TURBI	1,875	C-43/ CANAL 3

Table J-2. Surface Water Pump Information for Caloosahatchee Surface Water Usage.

Number	Water Use Permit	Pump	Location (State Planar) Easting	Northing	Intake Elevation (NGVD)	Diameter (in.)	Stat	Type	Capacity (GPM)	Water Source
211	2600603W	3	408985	870620	0	0	02	TURBI	2,000	C-43/ CANAL 3
212	2600603W	4	408985	870620	0	0	02	TURBI	2,000	C-43/ CANAL 3
213	2600603W	2	411615	870620	0	0	02	TURBI	2,500	C-43/ CANAL 3
214	2600603W	1	411615	870620	0	0	02	TURBI	2,500	C-43/ CANAL 3
215	3600003W	1	275370	868060	5.4	12	01	VERT	1,750	C-43
216	3600003W	2	275370	868060	5.4	14	01	VERT	3,000	C-43
217	3600003W	3	275370	868060	5.4	14	01	VERT	3,850	C-43
218	3600004W	1	306919	865343		3	01	CENTR	175	C-43
219	3600004W	2	306929	865355		3	01	CENTR	175	C-43
220	3600006W	1	310880	866836	-2	6	01	ELECT	400	C-43
221	3600006W	2	310098	866771	-2	3	01	CENTR	400	C-43
222	3600023W	1	306856	866591	11	5	02	CENTR	700	C-43
223	3600024W	1	298151	872501	0	6	01	CENTR	600	C-43/ CYPRESS
224	3600024W	2	298025	866896	0	4	01	CENTR	300	C-43
225	3600035W	1	271490	866770	1.5	18	01	VERT	7,000	C-43
226	3600035W	2	271490	866770	1.5	18	01	VERT	7,000	C-43
227	3600035W	3	271490	866770	1.5	18	01	VERT	7,000	C-43
228	3600035W	4	276000	868014			02			C-43
229	3600262W	1	306215	866840	10		01	CENTR	300	C-43
230	3600262W	2	308440	866775	10	10.44	01	CENTR	1,160	C-43
231	3600829W	1	295709	870372	-1	8	02	CENTR	1,250	C-43/ CYPRESS CREEK
232	3600829W	2	295737	870427	-1	8	02	CENTR	1,250	C-43/ CYPRESS CREEK
233	3601134W	1	314894	854013	20	9	02	CENTR	600	DOG CANAL
234	3601882W	1	306382	861803		2	02	CENTR	600	BEDMANS CREEK
235	3602064W	1	294203	867184	10		01		200	C-43
236	3602285W	1	300858	864497	0		01	CENTR	222	C-43
237	3602869W	1	273506	869156	5	2	02	CENTR	100	C-43
238	3602874W	1	245225	859430	10	6	02	CENTR	600	C-43
239	3602877W	1	248954	858059	10	6	02	CENTR	600	C-43/ ORANGE RIVER
240	3602934W	1	303017	864454	10	2	01	PHASE	60	BEDMANS CREEK CENTR 100 C-43

WCDs are privately held. The farms within the 298 Districts may have individual water-use permits and the irrigation pumps for those farms are described in the permits. The private WCDs have been permitted as a single entity and only the diversion pump is described in the permit. In the private WCDs, the individual farm pumps are not permitted and no information is available concerning those pumps.

The irrigation network includes the surface water pumps on the Caloosahatchee River and the pumps on the secondary canals that can draw water from the river. Although

it appears that there is a close connection between the canals and the water table aquifer, shallow ground water pumps are not included in the network.

The irrigation network includes several secondary and many tertiary canals (**Figure J-25**). The irrigation network was determined by locating all parcels that were permitted to use surface water from the secondary canals. The 1:24,000 scale hydrographic coverage was simplified to remove all flow paths that did not connect the permitted parcels to the river. The list of irrigation pumps was obtained from the SFWMD Water Use Division that contained all permitted surface water pumps as of December 1997. The surface water pumps located on the secondary canals were identified and converted into a GIS coverage. The irrigation network was extended to include the surface water pumps (**Figure J-26**).

There was little information available concerning the dimensions of the irrigation canals. Although some information is available concerning canal construction, the canal design descriptions are probably inaccurate due to erosion. Design descriptions were not available for all secondary canals. It was expected that this information could be found in the Plan of Reclamation for each WCD. Unfortunately, the plans could not be obtained as a single document from a public source.

# PRIMARY AND SECONDARY STRUCTURES AND CANALS

The canal system in the Caloosahatchee Basin consists of a primary canal system maintained by the SFWMD and several secondary canals that are maintained privately or by various Chapter 298 F.S. drainage districts. These drainage districts are special districts authorized to tax landowners for the purpose of drainage improvements or water management projects. The majority of the system is located in Hendry County and southern Glades County.

The Primary canal system consists of the C-43 Canal (Caloosahatchee River), C-19 Canal, C-20 and C-21 canals, and the L-1 and L-2 levee borrow canals. There are several structures on these canals, which are designed to maintain upstream water levels. The canals and water control structures were designed to provide 33 cfs mi^{-2} or 1.25 inches of drainage for the Caloosahatchee Basin. The operating conditions for these structures are given in **Table J-3**.

The secondary system consists of several canals that provide drainage or irrigation. For drainage, these canals were designed to provide the same drainage capacity as allowed by the USACE design for the entire basin. The design provided adequate drainage for their project area but did not provide capacity for upstream areas. The canals used for drainage have few water control structures to prevent over-drainage. The detailed design dimensions of the drainage systems are not generally available, and do not reflect the current canal dimensions because of erosion and sedimentation. Descriptions of the
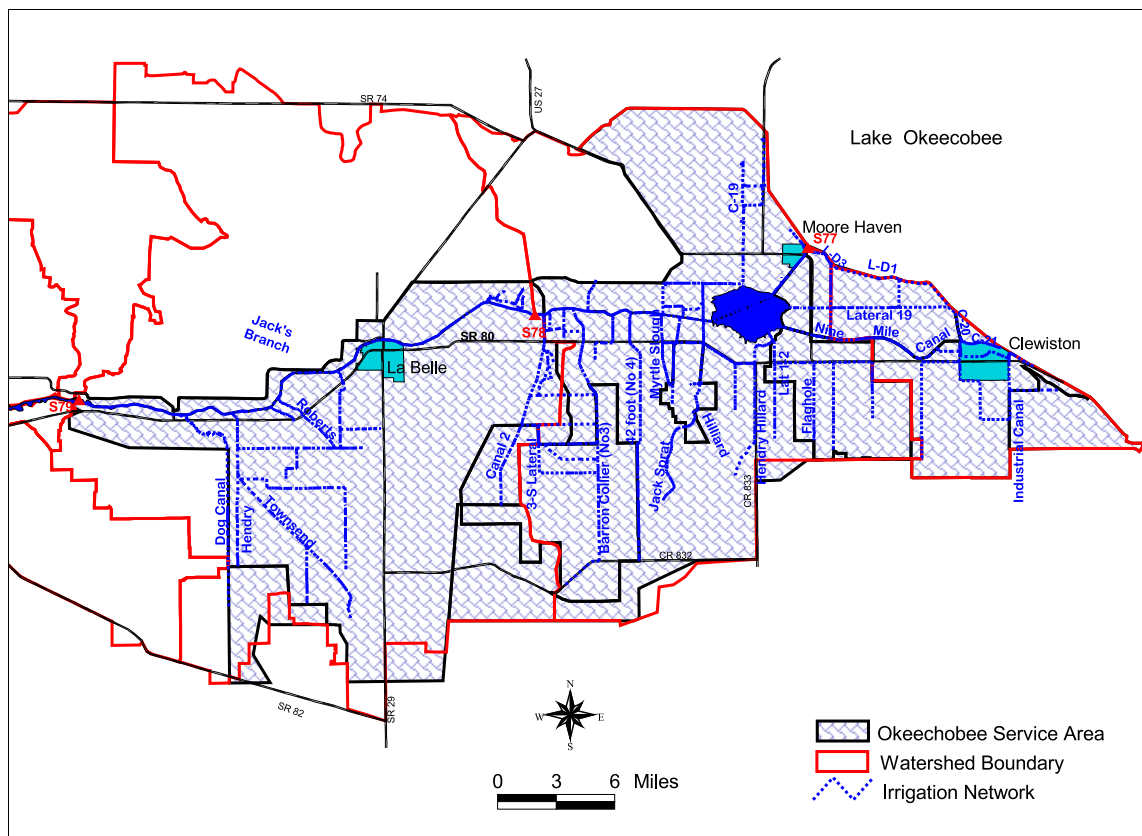
Figure J-25. Irrigation Canal Network for the Lake Okeechobee Service Area.
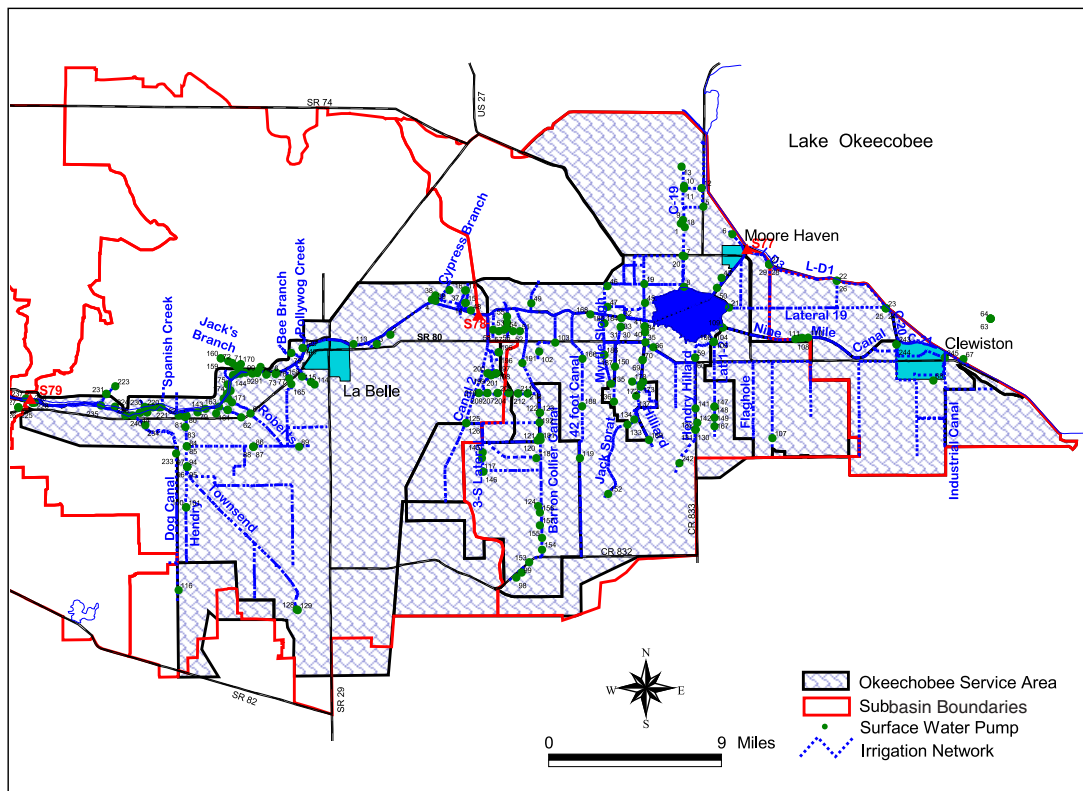
Figure J-26. Irrigation Canal Network and the Caloosahatchee River Water Pumps for the Lake Okeechobee Service Area.

Table J-3. Operating Schedules for the Primary Canal System.

Structure	Canal	Operating Rule
S77	C-43	Discharge rule follows Lake Okeechobee regulation schedule (see chart).
S-78	C-43	Maintain upstream canal stage between 10.8 and 11.3 feet NGVD.
S-79	C-43	Maintain upstream canal stage between 2.8 and 3.4 feet NGVD. Rules allow lowering stage to 2.2 feet to accommodate anticipated runoff, however stage maintained above 2.5 feet to provide water for Lee County water supply intakes.
S-47D	C-19	Maintain upstream water between 12.5 and 13.0 feet NGVD.
S-47B	C-19	Maintain upstream water between 14 and 15.5 feet NGVD.
S-342	C-19	Maintain upstream water above 16 feet NGVD.
C-5		Release water from lake when Lake Okeechobee is above 14.5 feet and Nicodemus Slough is low.
C-5A	L-41	Release water from lake when Lake Okeechobee is above 14.5 feet and basin is below 12.0 feet NGVD.
S-235	C-43 & LD1	Kept open when possible to provide water and drainage for S-4 Basin. Stage maintained in S-4 borrow canals 11-14 feet NGVD.
S-4	L-21	Pump storm water runoff into lake when stage in C-20 exceeds 14 feet NGVD.
S-169	L-21	Left open to lake when the lake is below 13.5 feet.
S-310	L-21	Left open when the lake is below 13.5 feet.

discharge control structures are provided in **Table J-4** and the locations of the structures is provided in **Figure J-26**.

Table J-4. Drainage Controls Structures on Secondary Canals of Caloosahatchee Basin upstream of S-79.

Number	Project Name	SW Permit	Type of Structure	Inlet Width/ Diameter	Inlet Height	Control Elevation
430	Gerber Groves	26-179	cmp w/riser	2-73"	44"	23.8
438	Barron WCD	26-176	cmp w/fbr	3-90"		
305	Gerber Groves	26-00179	sheet Pile Weir			20.61
452	Gerber Groves	26-179	weir	30'	19'	
453	Barron WCD	26-176	cmp w/fbr	5-77"	44"	
454	Barron WCD	26-176	weir w/fbr			
439	Barron WCD	26-176	pumps	2		
455	Barron WCD	26-176	cmp w/fbr	5-77"	44"	
294	C-4 Canal	C-4	cmp	5-72"		
293	C-4 Canal	C-4	cmp	4-60"	40'	
71	Alico Inc.	26-315	weir w v-notch orifice	0.5	na	
73	Alico Inc.	26-315	weir w v-notch orifice		0.4	na
296	Alico Inc.	26-108	cmp	2-60"		
431	Gerber Groves	26-179	cmp w/riser	3-72"x50'"		21
430	Gerber Groves	26-179	cmp w/riser	2-73"	"44"	23.8
274	LPDD	Townsend	wier			
276	LPDD	Townsend	wier			
285	CPI-LPDD	Townsend	cmp			
282	LPDD	Townsend	BCWw/FBR			
334	ECWCD S-H-1	Bedman	BCWw/FBR			
281	LPDD	Townsend	BCWw/FBR			
465	Clewiston DD		gated culvert	72"	"66"	
466	Sugarland Main		screw gates	2-5'x10'	7'	15
467	S-310	C&SFFCD	lock			
468	S-169	C&SFFCD	cmp w/gates	3-84"		15.5'
469	Culvert 2	C&SFFCD	culvert			
470	S-4	C&SFFCD	pump			
471	S-236	C&SFFCD	pump			
472	CU-5	C&SFFCD	culvert			
473	S-47B	C&SFFCD	culvert			
474	S-342	C&SFFCD	culvert			
475	CU-5A	C&SFFCD	culvert			
476	S-47D	C&SFFCD	spillway			
477	S-78	C&SFFCD	spillway			
478	S-79	C&SFFCD	splock			
479	S-77	C&SFFCD	spillway			
480	S-235	C&SFFCD	culvert			

For irrigation there are pump stations on several canals (Townsend, Canal 3, Canal 4, Hilliard, Hendry-Hilliard, and Flaghole). These pump stations are designed to raise the water levels in the upstream canal segments to make water available for farm-level irrigation pumps to withdrawal water from the canal. The pumps are operated on float-switches to maintain canal levels during critical dry periods. The pumps are located at structures that include weirs with gates or movable boards that facilitate drainage during wet periods. The location of the pumps is provided in **Figure J-27** and descriptions of the diversion pumps are provided in **Table J-5**.
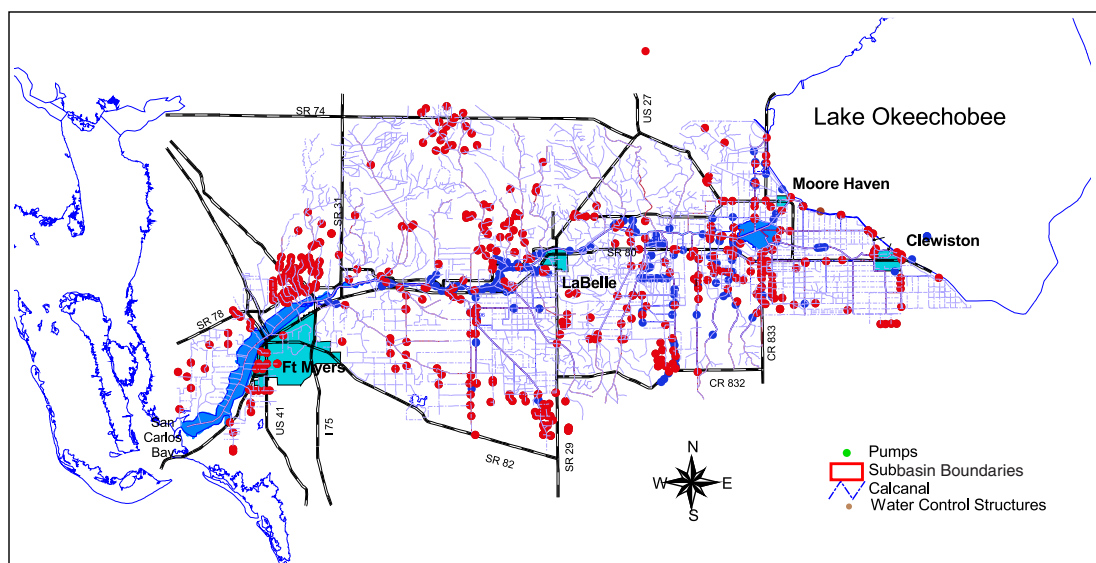
Figure J-27. Water Control Structures on the Primary and Secondary Canal System of the Caloosahatchee Basin.

ACKNOWLEDGEMENTS

This report was produced with support from Puneet Srivastava, Fawn Grigsby, Angela Alexander, and Chad Neuseelhorf.

REFERENCES

Flaig, E.G., P. Srivastava, and J.C. Capece. 1998a. *Analysis of Water and Nutrient Budgets for the Caloosahatchee Watershed*: *Task 6: Verification of Subbasin Boundaries*. University of Florida and South Florida Water Management District.

Flaig, E.G. and J.C. Capece. 1998b. Uncertainty Associated with Hydrologic Simulation of Different Soil Types in Southwest Florida. Manuscript prepared for publication.

Flaig, E.G. and J.C. Capece. 1998c. *Analysis of Water and Nutrient Budgets for the Caloosahatchee Watershed. Task 6: Verification of Selected Coverages*. University of Florida and South Florida Water Management District.

Table J-5. Secondary Irrigation and Drainage Pumps in the Caloosahatchee Basin.

Number	Water Use Permit	Intake Elevation (NGVD)	Upstream Elevation	Diameter (in.)	Type	Capacity	Water Source
154	2600315W	21	29	8	AXIAL	1,000	C-3
104	2600139W	na	17	48	na	na	C-43
105	2600139W	na	17.5	48	na	na	C-43
106	2600139W	na	17.5	42	na	na	C-43
59	2600003W	9	14.5	60	AXIAL	100,000	HILLIARD CANAL
60	2600003W	9	14.5	60	AXIAL	100,000	HILLIARD CANAL
130	2600234W	14.5	21	8	na	1,500	C-43/ H-H CANAL
131	2600234W	14.5	21	8	na	1,500	C-43/ H-H CANAL
132	2600234W	14.5	21	54	na	40,000	C-43/ H-H CANAL
40	2200189W	11	17	48	AXIAL	50,000	HILLIARD CANAL
41	2200189W	11	17	48	AXIAL	50,000	HILLIARD CANAL
42	2200189W	11	17	48	AXIAL	50,000	HILLIARD CANAL
36	2200135W	12.5	na	24	AXIAL	12,000	C-43
191	2600510W	12.5	14	na	AXIAL	150,000	C-43/ CANAL 3
122	2600176W	14.5	20	54	AXIAL	75,000	C-43/ CANAL 3
123	2600176W	14.5	20	54	AXIAL	75,000	C-43/ CANAL 3
120	2600176W	14	18.5	54	AXIAL	75,000	C-43/ CANAL 3
121	2600176W	14	18.5	54	AXIAL	75,000	C-43/ CANAL 3
125	2600179W	18.5	21	30	AXIAL	1,5000	C-43/ CANAL 3
126	2600179W	18.5	21	30	AXIAL	15,000	CANAL 3
84	2600082W	na	21	36	na	40,000	TOWNSEND CANAL
85	2600082W	na	21	36	na	40,000	TOWNSEND CANAL
86	2600082W	na	21	20	na	11,000	TOWNSEND CANAL
87	2600082W	na	na	20	na	11,000	TOWNSEND CANAL
88	2600082W	na	na	20	na	11,000	TOWNSEND CANAL
89	2600082W	na	na	36	na	40,000	TOWNSEND CANAL
94	2600106W	10	22	36	AXIAL	28,000	C-43
95	2600106W	10	22	36	AXIAL	28,000	C-43
96	2600106W	10	22	36	AXIAL	2,8000	C-43
97	2600106W	10	22	36	AXIAL	28,000	C-43
128	2600222W	22	na	10	CENTR	3,500	TOWNSEND CANAL
129	2600222W	22	na	10	CENTR	3,500	TOWNSEND CANAL
22	2200063W	7	10.5	52	CENTR	70,000	LD-1
23	2200063W	7	10.5	36	VERT.	30,000	LD-1
24	2200063W	7	10.5	36	VERT.	30,000	LD-1
25	2200063W	7	10.5	36	VERT.	30,000	LD-1
26	2200063W	7	10.5	52	CENTR	70,000	LD-1
27	2200063W	7	13.5	52	CENTR	56,000	LD-3
28	2200063W	6	13.5	30	VERT.	18,000	LD-3
29	2200063W	9	13.5	52	CENTR	56,000	LD-3
67	2600024W	6	13.5	12	CENTR	5,000	OKEECHOBEE
68	2600024W	15	14	16	MIX F	5,000	LATERAL NO.16
243	Sugarland	15	13			45,000	C-21
244	Clewiston	16	13			65,000	C-21
245	Clewiston	11	13.5			37,000	INDUSTRIAL CANAL

SUPPLEMENTAL INFORMATION

Drainage and Irrigation Data and Coverages

The data and coverages developed as part of this task are available on the University of Florida, Southwest Florida Research and Education Center anonymous ftp site: arc.imok.ufl.edu/pub/wqgis. The following data stored as zipped files are located at that site:

Surface and ground water well coverages for Charlotte, Glades, Hendry, and Lee counties:

Chwell97.zip

Glwell97.zip

Hewell97.zip

Lewell97.zip

Irrigation network:

Pump data excel-file

Arc/view shape files describing irrigation network:

Canal.zip

Drainage network:

Drainage network coverage (Caltrib.zip)

Flowpaths descriptive document (flowpaths.doc)

Drainage control structure data excel-file (structfin.xls)

Soil-Landscape coverages:

County coverages (Hescape.zip, Glscape.zip, Lescape.zip, Chscape.zip)

MikeShe soil-landscape physical properties database. (Florsoil.zip)

Soil-landscape document. (Soilsdata.doc)

Drainage Control Structures in the Caloosahatchee Basin

The list below contains the available information describing the drainage control structures in the basin. These structures include control structures for farms and urban projects that have surface water permits, primary structures on the primary canal system, and significant bridges and culverts that affect flow.

ID	Structure number from coverage
East	State Plane Coordinates, Florida East, Easting
North	State Plane Coordinates, Florida East, Northing
Project Name	Name of project owner, urban subbasin, or WCD
SW Permit	SFWMD surface water permit number
Type of Structure	Type of discharge structure
Inlet Width/Diameter	Width or diameter of structure (feet)
Inlet Height	Height of the structure opening (feet)
Control Elevation	Control elevation for water release (feet NGVD)
Crest Elevation	Elevation of top of structure (feet NGVD)
Orifice Dimension	Dimensions of bleeder orifice (feet)
Discharge Diameter	Diameter of discharge structure for weirs and drop inlets (feet)
Discharge Length	Length of discharge culvert (feet)
Ring Diameter	Diameter of ring bleeder structure (feet)
Capacity	Discharge capacity for structure
SW per Area	Permitted area for surface water project (acres)
Farm Area	Area of farm within surface water permit (acres)
Reservoir Area	Reservoir area in surface water permit (acres)
Allowable Discharge	Allowable discharge for the permitted area
Crop	Crop for farmed area
Ditch Spacing	Drainage ditch spacing (feet)
Ditch Depth	Drainage ditch depth and width (feet)

Appendix K
ASSESSMENT OF CALOOSAHATCHEE DESIGN ELEMENTS IN THE RESTUDY AND THE LOWER EAST COAST REGIONAL WATER SUPPLY PLAN USING REVISED CALOOSAHATCHEE HYDROLOGY

K. Konyha
South Florida Water Management District

SUMMARY

Recent hydrologic studies done for the *Caloosahatchee Water Management Plan* (CWMP) show less runoff and more demand in the Caloosahatchee Basin, as compared to estimates used in the *Lower East Coast Regional Water Supply Plan* (LEC Plan). These changes affect the LEC Plan by greatly reducing the available water in the basin. This memorandum describes an assessment of the performance of the reservoir - aquifer storage and recovery (ASR) - backpumping facilities proposed by the LEC Plan using revised Caloosahatchee hydrology. In this analysis, it was assumed that water supply releases from Lake Okeechobee to the Caloosahatchee Basin are restricted to 29,000 acre-foot per year. The study finds the following:

1. The proposed facilities would only provide a 1-in-3 level of drought protection for the 175,000 acres of irrigated land anticipated in the CWMP 2020 scenario.

2. The proposed facilities could provide a 1-in-10 level of drought protection for 120,000 acres of irrigated land.

3. By increasing the reservoir capacity to 220,000 acre-foot, the proposed facilities could provide a 1-in-10 level of drought protection for the 175,000 acres of irrigated land anticipated in the CWMP 2020 scenario.

4. Backpumping to Lake Okeechobee may not be practical under the assumptions in some 2020 scenarios, but remain a viable option in others.

BACKGROUND

Motivation for the CWMP Reassessment of Caloosahatchee Hydrology

During the development of the LEC Plan it was determined that there was a need to reassess the estimates of Caloosahatchee runoff and demands used in water supply modeling. This is important to the LEC Plan because agricultural stakeholders believed that 2020 demand estimates for the Caloosahatchee needed to be reanalyzed.

Previous demand and runoff estimates were developed from reliable flow data but the lack of reliable information on landuse, in particular landuse within the Lake Okeechobee Service Area (LOSA), made estimates of future demands problematic. Consequently, the CWMP was tasked with reassessing the hydrology in the Caloosahatchee.

This reassessment has been completed (Konyha and Flagg, draft; Owasina, Dabbs, and Jansen, draft). This reassessment is based on more detailed landuse information and a determination of surface irrigated lands in LOSA. The reassessment uses deterministic hydrologic modeling of all lands in the watershed over a 31-year period. The source of irrigation water (ground water or C-43 water) is considered in the analysis. The new estimates of runoff and demands are substantially different from the earlier estimates. They show substantially less available water (i.e., runoff minus demands) in the Caloosahatchee Basin than was assumed in the Restudy and initial runs of the LEC Plan. A comparison of the two estimates is shown in **Table K-1**. The estimate of 2020 demands has increased by 67,000 acre-foot per year (+53 percent) while the estimate of runoff has decreased by 143,000 acre-foot per year (-18 percent).

Table K-1. Comparison of Average Annual Demand and Runoff from the East and West Caloosahatchee Basin (1965-1995 Climate).[a]

	Old Estimates (Used in Restudy and LEC Plan)		New Estimates (Used in CWMP)	
	Demand	**Runoff**	**Demand**	**Runoff**
1995 Land use	89,518	814,883	112,449	674,711
2020 Land use (LEC Plan)	111,000	814,937	192,253	671,689
2050 Land use (RESTUDY)	125,334	814,937	---	---

a. Units are acre-foot per year.

The new estimates of runoff (670,000 acre-foot per year) are not substantially different from 1972-1995 measured basin runoff (650,000 acre-foot per year). Approximately half of the differences in demands are caused by revisions in future land use and half result from methodological differences. The revised estimates are preferred over the previous estimates.

Potential Impact of the Revised Hydrology on Existing Restudy Design Elements

To date, Restudy and LEC Plan analyses have had to rely on the old estimates in their modeling efforts. The changes in runoff and demand are large and may affect the performance of the design components being recommended by the LEC Plan. This study assesses the performance of Restudy Design Elements for the Caloosahatchee using the new estimates of demand and runoff developed by the CWMP.

Summary of Existing Restudy Design Elements

The Restudy has proposed a development of local water resources to reduce the basin's reliance on Lake Okeechobee waters. Local water resources would be developed using three methods: a regional reservoir, a set of ASR wells, and a set of pumps to lift local runoff water back into Lake Okeechobee. A brief description of these three design elements follows.

Reservoir - The reservoir is 10,000 acres in area with a 16-feet depth and a capacity of 160,000 acre-foot. Waters are pumped from the C-43 Canal into the reservoir using a pump with 2,500 cubic feet per second (cfs) capacity. The reservoir is located in the West Caloosahatchee Drainage Basin. The operating rules for the reservoir are based on reservoir storage and basin runoff.

ASRs - There are 22 sets of ASR wells each with a capacity of 10 million gallons per day (mgd), and together they have a total capacity of 220 mgd. These inject waters from the reservoir or withdraw waters from the ASRs. A 75 percent recovery is assumed regardless of the period stored underground. It is assumed that there is no mixing with higher salinity aquifer water. The operating rules of the ASRs are based on reservoir storage.

Backpumping - A set of pumps near the S-78 Structure lift waters from the reservoir and the West Caloosahatchee Basin into the East Caloosahatchee Basin. A second set of pumps lift waters from the East Caloosahatchee Basin through a storm water treatment area into Lake Okeechobee. The pump capacity of these facilities is 1,000 cfs. Operating rules for the pumps are based on the reservoir storage volume.

> Note: These are generic design elements that may be replaced by alternate design elements in the future. For example, the number of reservoirs, their location(s), the size of ASR's, or the development of wellfields in lieu of reservoirs are all potential alternatives to the generic design elements discussed here. All are consistent with this analysis in the sense that all develop the local water resource.

PROBLEM STATEMENT

This paper assesses the performance of the proposed Reservoir - ASR - Backpumping facilities using the revised estimates of Caloosahatchee Basin runoff and demands. The assessment asks three questions: how well would the system perform; how much land could the system adequately irrigate; and what size reservoir would be needed to provide adequate irrigation?

Assessment #1: Describe the performance of the existing Restudy Design Elements

The objective of this assessment is to determine the level of service that would be provided by the Restudy Design Elements as described above. Because runoff has decreased and irrigation has increased, the level-of-service will be below the desired 1-in-10. Because there is competition between irrigation demands and estuarine needs it is assumed, a priori, that estuarine needs will be met even though irrigation demands are not met.

Assessment #2: Determine the maximum irrigated land area that could be supplied at a 1-in-10 level of service using the existing Restudy Design Elements

The objective of this assessment is to determine the acres of land that can be irrigated by the C-43 while still meeting the desired 1-in-10 level of service and also meeting estuarine needs.

Assessment #3: Determine the reservoir size needed to meet revised CWMP 2020 demands with a 1-in-10 level of service

The goal of the LEC Plan is to achieve a 1-in-10 level of service for all anticipated future water supply needs. This objective of this assessment is to describe one method of meeting that requirement. For the purpose of this study, the size of the reservoir will be increased until both water supply demands and estuarine needs can be met.

METHODOLOGY

Modeling Approach

A computer model called OPTI-5 is used for these analyses. The model determines operational rules for storage/release systems (i.e. reservoir, ASRs, and backpumping facilities). The goal of the model is to find operational rules that simultaneously supply the irrigation demands in the basin and also meet the environmental criteria for the Caloosahatchee Estuary. This type of model is well suited for situations where there is competition for a resource. In this case, the competition is between human demands and estuarine needs and the resource is watershed runoff. This model was written for the District under contract by John Labadie (1997).

The Caloosahatchee Optimization model requires three operational rules: a reservoir rule, an ASR rule, and a backpumping rule. The operational rule for the reservoir describes when water is pumped to/from the reservoir and how much is pumped. The operational rule for the ASRs describes when ASR water is injected/withdrawn. The operational rule for backpumping describes when and how much water is withdrawn from the reservoir and sent back to Lake Okeechobee.

The model uses a Genetic Algorithm to select the operational rules, testing the performance of the system using a 31-year period of runoff and demands. The performance is tested using two performance measures: one for water supply, and one for estuarine needs. Many different rules are generated and tested. In this exercise, the Optimization model generated and tested 30,000 different sets of rules for each simulation. Each simulation takes about two hours using a high speed PC.

Performance Measures and Targets

Level of Service for Water Supply

The performance measure for water supply is the level of service, and the desired water supply target is a 1-in-10 level of service. The level of service (l.o.s.) is defined as:

l.o.s. = (years when all supplies are met)/(years simulated)

Because the model simulates 31 years of watershed behavior, the 1-in-10 criteria is met if the system can provide all water demands for 28 of the 31 years simulated (l.o.s. = 28/31 = 0.9). The model also tracks demands unmet. This performance measure is equivalent to one used in the LEC Plan planning process.

Estuary Protection Criteria

Estuary Performance Measure

The performance measure for estuarine protection is the distribution of monthly flows to the estuary. The monthly flow distribution is determined by calculating the average monthly flow for each month simulated and then counting the number of occurrences in selected flow ranges. This measure only has value if a sufficiently long period of climate is simulated. The period of record for these simulations is 31 years.

Estuary Performance Targets

The performance of a model is determined by comparing the modeled flows to the estuary (the performance measure) against a target flow distribution. The target flow distribution for the Caloosahatchee Estuary is presented in **Table K-2**.

Any simulation that has fewer than 60 months of flows below 300 cfs, and fewer than 22 months of flows between 2,800 and 4,500 cfs, and fewer than 6 months of flows

Table K-2. Target Flow Distribution (31-year period).

Flow Range	Frequency Distribution (percent)	Number of Occurences	Problem Caused
0 to 300 cfs	16	<60	High salinity damages freshwater tolerant seagrasses
300 to 2,800 cfs	76	284	None
2,800 to 4,500 cfs	6	<16	Low salinity damages saltwater tolerant seagrasses in estuary
> 4,500 cfs	2	<6	Low salinity damages seagrasses outside estuary (where salinity is normally >30 ppt)

above 450 cfs meets the estuary performance target. This performance target is identical to that used in Restudy and the LEC Plan. The performance target was developed by biologists studying the estuary (Chamberlain et. al, 1998) and is based on the frequency of harm experienced by seagrasses in a natural system. This 'natural' flow is log-normally distributed and represents an average annual flow of about 650,000 acre-foot per year. This volume is equal to the average 1965-1995 basin runoff.

Estuary Modeling Targets

The flow distribution targets used in the optimization model are not the same as the performance targets above. If performance targets were used, they would force the model to provide an average flow of 650,000 acre-foot per year to the estuary. However, the estuarine ecosystem does not need this much water. The undeveloped watershed probably had at least 100,000 acre-foot less runoff than today's watershed (4 inches more evapotranspiration from the 250,000 acres of former wetlands and forest that are now pasture and grazing lands). Biologists have made an evaluation of minimal flows required by Caloosahatchee Watershed (Haunert, Doering, and Chamberlain, draft) that shows that a much smaller volume of water could meet estuarine needs - if the distribution of the flow remained log-normal. This modeling target distribution is shown in **Table K-3**.

This distribution is used in all optimization modeling in this paper. This is also the distribution used in developing the Restudy Recommended Plan (Alt D13R) and the preferred LEC Plan. This distribution of flow represents an average annual flow of about 450,000 acre-foot per year. The difference between the measured basin runoff (650,000 acre-foot per year) and this minimal flow distribution (450,000 acre-foot per year) defines the water available in the watershed for development. This available water (200,000 acre-foot per year) is roughly equivalent to the proposed 2020 demands from the C-43 Canal (192,000 acre-foot per year). It is this water that is captured by the reservoir-ASR-backpumping system and redirected to meet water supply needs.

Table K-3. Modeling Target Flow Distribution (31-year period).

Flow Range	Frequency of Occurrence (percent)	Number of Occurrences
0 to 300 cfs	10	37
300 to 660 cfs	55	205
660 to 925 cfs	20	74
925 to 1,550 cfs	10	37
1,550 to 2,175 cfs	3	11
2,175 to 2,800 cfs	2	6
2,800 to 4,500 cfs	1	2

Assumptions Made in These Simulations

In the time frame available, it was not possible to assess all of the potentially viable methods of providing the additional irrigation water supply, therefore, the following assumptions were made:

- Lake Okeechobee deliveries are held constant and equal to the deliveries of the SFWMM simulation called 'sfwmm_2020wr'. This simulation provides about 30,000 acre-foot per year from the lake for irrigation in the C-43 Basin.

- ASRs are not expanded. The capacity of the ASR wells is kept at 220 mgd.

- Estuarine protection criteria will not be changed. Further, protection of the estuary will be given priority over water supply criteria.

- Increased demands will be met through expansion of the regional reservoir.

- For the purpose of this analysis, it is acceptable to reduce backpumping. Any impact of reduced backpumping on the regional system is not considered in this analysis.

ASSESSMENTS

Assessment #1: Describe the Performance of the Existing Restudy Design Elements

This analysis examines the performance of the Caloosahatchee system using the revised runoff and demand data while keeping the reservoir capacity at 160,000 acre-foot. Other Restudy elements are also unchanged. The object of this analysis is to determine

what level of drought protection can be provided and also to determine if the estuary protection criteria can be met.

Drought Protection Performance

The assessment shows that, with the revised demands, the proposed 160,000 acre-foot reservoir will not be able to meet demands at a 1-in-10 level of service. The lake provides 29,000 acre-foot per year of the total 192,000 acre-foot per year, leaving 163,000 acre-foot of demands for the basin. The existing system can provide 138,000 of (85 percent) this demand but the timing of these deliveries (**Table K-4** and **Figure K-1**) are such that the basin goes into water shortage on 13 of the 31 years, giving a projected level of service of only 58 percent.

Table K-4. Average Annual Demands and Supplies and Level of Service.

Total C-43 Demands (acre-foot per year)	Lake Supplies (acre-foot per year)	Local Supplies (acre-foot per year)	Demands Unmet (acre-foot per year)	Level of Service (percent)
192,253	29,241	137,610	25,401	58

Estuarine Performance

The assessment shows that the proposed system can still meet environmental flow targets. However, the OPTI-5 model found backpumping to be ineffective in meeting estuarine performance targets. Backpumping was modeled as a process in the OPTI-5 model but the model decided that the best way to use the water was by turning backpumping off. The model's decision to not use backpumping is due in part to the modeling assumption that backpumped waters would not be used to meet future water supply needs. In the past, backpumping was effective because there was considerably more available water in the basin and backpumping could reduce the number of high flow months. With the higher demands and lower runoff estimates used in this analysis, there is too little excess water to backpump.

Table K-5 and **Figure K-2** show the distribution of monthly flows for the new hydrology (2020 Base) and for the system with the existing Restudy elements. Low flows have been increased and high flows decreased.

Table K-5. Estuarine Flows and Distribution.

2020 Base Runoff (acre-foot per year)	Runoff with Restudy Elements (acre-foot per year)	Backpumping Volume (acre-foot per year)	Flow Distribution		
			<300 cfs	2,800-4,800 cfs	>4,800 cfs
769,124	593,230	0	66	16	7
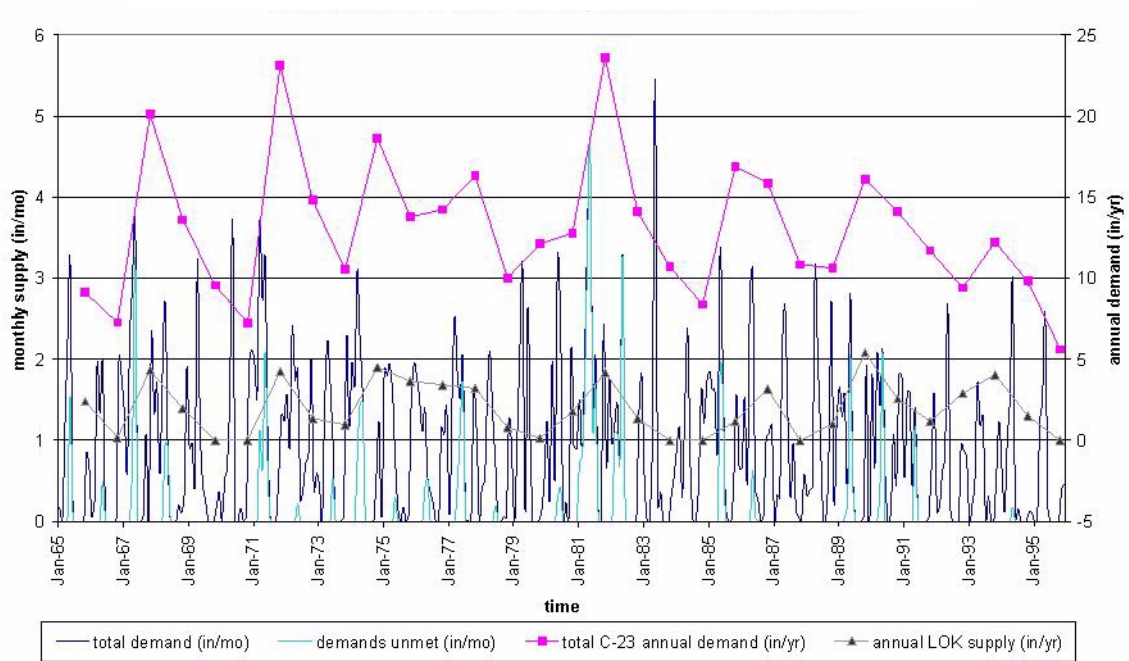
Figure K-1. Drought Protection Performance for Assessment #1.
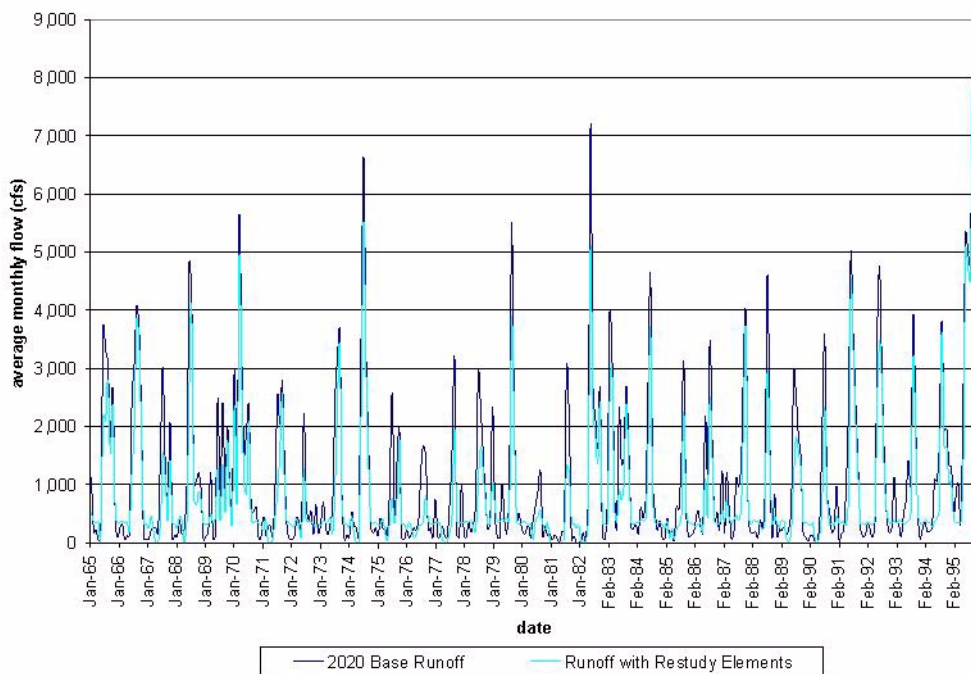
Figure K-2. Estuarine Performance for Assessment #1.

Assessment #2: Determine the Maximum Irrigated Land Area Supplied at a 1-in-10 L.O.S. with the Existing Restudy Design Elements

In the second assessment, the reservoir size is kept at 160,000 acre-foot and the irrigation demand is reduced until a 1-in-10 level of service can be maintained. This required several simulations as the irrigation demands were varied, only the final, acceptable, run is described here.

Drought Protection Performance

This assessment found that the existing Restudy Design Elements could supply (at a 1-in-10 l.o.s.) an irrigation demand of about 135,000 acre-foot per year (29,000 from the lake and 101,000 from the basin) (**Table K-6**). This compares to a 1995 C-43 demand of 112,000 acre-foot per year and a 2020 demand of 192,000 acre-foot per year. This is roughly equivalent to 120,000 acres irrigated by the C-43 Canal and compares to 103,000 acres irrigated by the C-43 in 1995 and a projected 177,000 acres irrigated by the C-43 in 2020.

Table K-6. Average Annual Demands and Supplies and Level of Service.

Total C-43 Demands (acre-foot per year)	Lake Supplies (acre-foot per year)	Local Supplies (acre-foot per year)	Demands Unmet (acre-foot per year)	Level of Service (percent)
135,350	29,241	100,640	5,469	87

Estuarine Performance

The assessment shows that the proposed system can still meet environmental flow targets. In this case, the OPTI-5 model found 58,000 acre-foot per year of water available for backpumping. Backpumping occurs on 112 of the months in the simulation (about 2 months per year) and seems to be effective in reducing estuarine flows during high flow months, thus allowing the reservoir to be utilized for water supplies. If flows from the lake were allowed to increase as a result of this backpumping, a larger acreage could be supported by this reservoir.

Table K-7 and **Figure K-3** show the distribution of monthly flows for the new hydrology (2020 Base) and for the system with the existing Restudy elements. Low flows have been increased and high flows decreased. Backpumping is also shown on this figure.

Table K-7. Estuarine Flows and Distribution.

2020 Base Runoff (acre-foot per year)	Runoff with Restudy Elements (acre-foot per year)	Backpumping Volume (acre-foot per year)	Flow Distribution		
			<300 cfs	2,800-4,800 cfs	>4,800 cfs
769,124	582,988	58,323	49	15	5

Assessment #3: Determine the Reservoir Size Needed to Meet Revised CWMP 2020 Demands with a 1-in-10 L.O.S.

In this assessment, demands are set equal to the revised 2020 demands (192,000 acre-foot per year) and the size of the reservoir is increased until a 1-in-10 l.o.s. is achieved. This required several simulations but only the final run is described here.

Drought Protection Performance

The assessment found that a 220,000 acre-foot reservoir was needed to provide water supplies at a 1-in-10 level of service. **Table K-8** and **Figure K-4** show the performance of this system.

Table K-8. Average Annual Demands and Supplies and Level of Service.

Total C-43 Demands (acre-foot per year)	Lake Supplies (acre-foot per year)	Local Supplies (acre-foot per year)	Demands Unmet (acre-foot per year)	Level of Service (percent)
192,253	29,241	154,945	8,056	90

Estuarine Performance

The modified system can also meet the estuarine performance targets. Although the performance shown in **Table K-9** is marginal, it is believed that minor additional modifications of the OPTI-5 model parameters would provide an acceptable performance. (Lack of time precluded these additional modifications). The high demands decrease available water in the basin, and therefore (as with assessment #1), the OPTI-5 model found backpumping to be ineffective under the assumptions modeled.
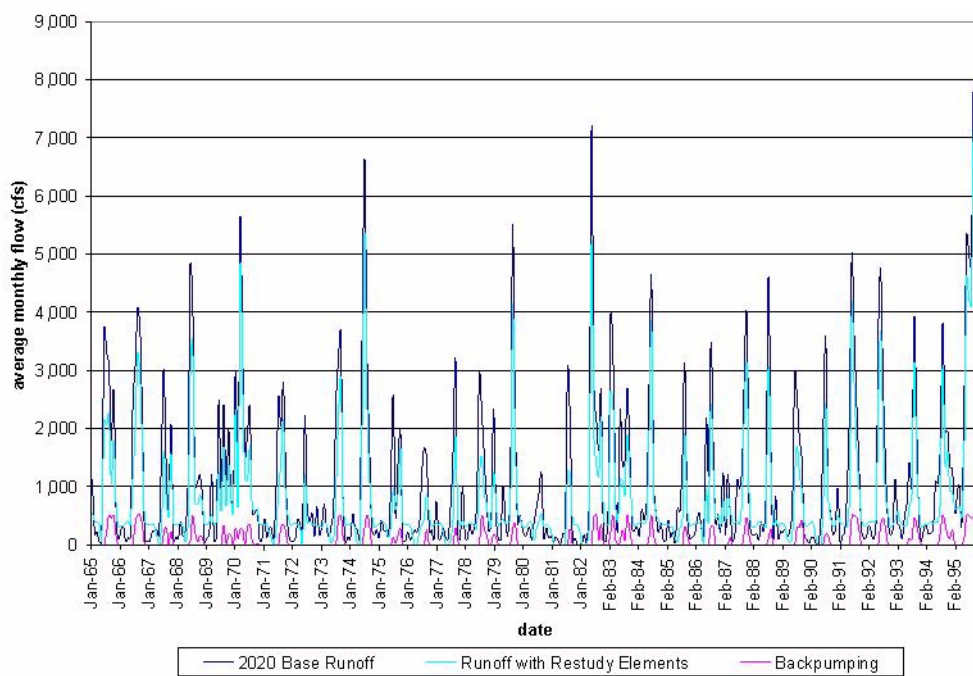
Figure K-3. Estuarine Performance for Assessment #2.
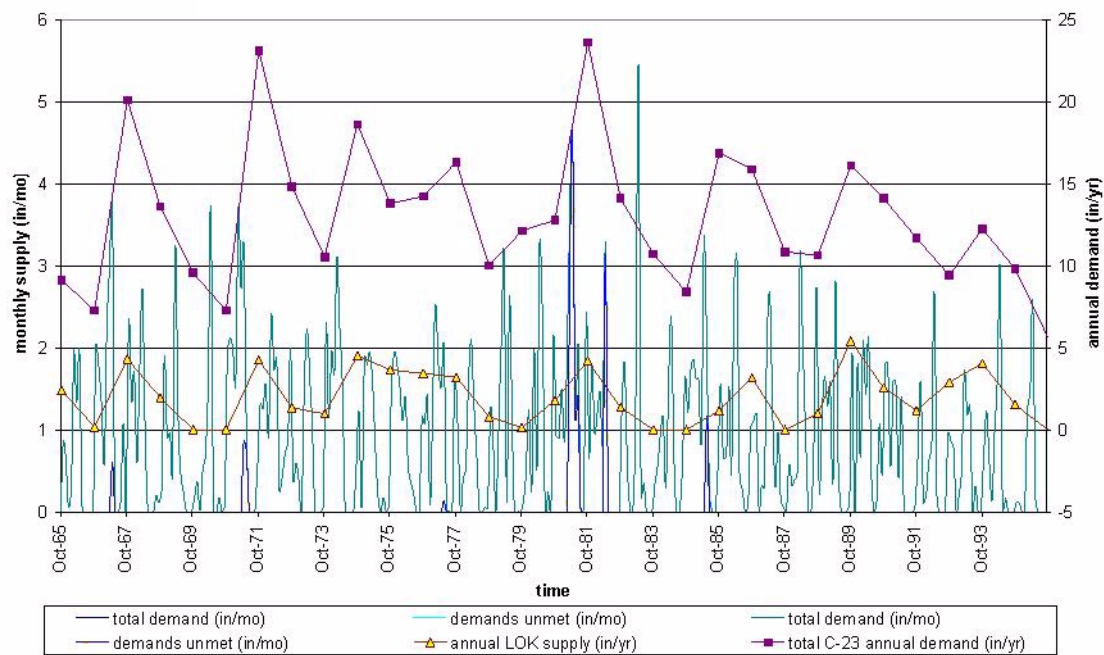
Figure K-4. Drought Protection Performance for Assessment #3.

Table K-9. Estuarine Flows and Distribution.

2020 Base Runoff (acre-foot per year)	Runoff with Restudy Elements (acre-foot per year)	Backpumping Volume (acre-foot per year)	Flow Distribution		
			<300 cfs	2,800-4,800 cfs	>4,800 cfs
769,124	570,466	0	64	20	6

Table K-9 and **Figure K-5** shows the distribution of monthly flows for the new hydrology (2020 Base) and for the system with the larger reservoir. These flows are similar to those of assessment #1 and assessment #2.

CONCLUSIONS AND RECOMMENDATIONS

Description of One Water Management System That Satisfies Environmental and Water Supply Performance Measures

The above analyses show that approximately 60,000 acre-foot of additional storage may be needed for the Caloosahatchee Basin. Expanding the proposed 160,000 acre-foot reservoir to 220,000 acre-foot will provide this storage. Optimization modeling shows that this modification would result in a system capable of meeting both water supply needs and the environmental needs of the estuary.

Recommendations for Future Work

Expansion of the reservoir is only one solution, it is not necessarily the best solution. There are other ways to develop local water resources (increased use of ground water, distributed reservoirs, backpumping to Lake Okeechobee, etc.) and these options should be explored.

The three assessments produce very similar outflow volumes (593,000 acre-foot per year [ac-ft/y], 583,000 ac-ft/y, and 570,000 ac-ft/y). When compared against the 450,000 acre-foot per year outflow volume of the estuary modeling target distribution, it seems that the system as modeled cannot capture all major runoff events and this implies that available water is still being lost to tide. Further work is needed to assess if it is practical to capture some of these lost waters.

The performance measures used in these analyses are likely to undergo revisions. Ongoing estuarine research may cause modifications in the estuarine performance measures, particularly the modeling performance targets. Since these targets define the available water in the basin, such changes could have a significant impact. The suitability of the water supply criteria also needs further work.
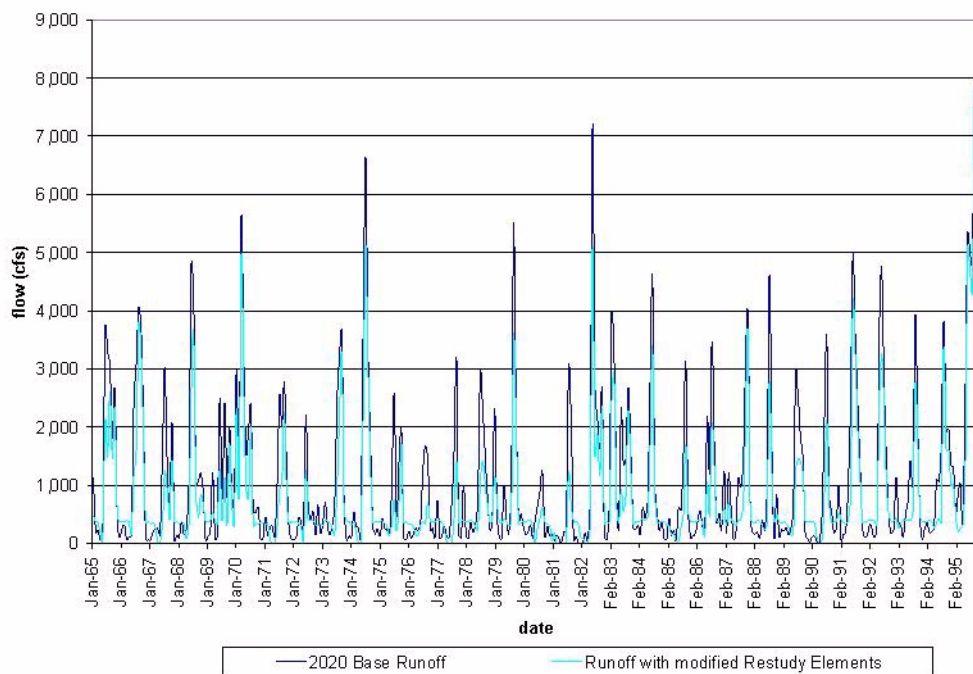
Figure K-5. Estuarine Performance for Assessment #3.

The revised demands and runoff used here are considered to be an improvement over previous estimates. Better and more detailed hydrologic modeling is still required for this basin.

Appendix L
AFSIRS/WATBAL WATER BUDGET MODEL

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### South Florida Water Management District

INTRODUCTION

The AFSIRS/WATBAL hydrologic model was developed for the *Caloosahatchee Water Management Plan* (CWMP) to estimate current and future water demand. It is a comparatively simple water budget model based on the model Agricultural Field Scale Irrigation Requirements Simulation (AFSIRS) (Smajstrla, 1990). All major components of the hydrologic cycle are determined in AFSIRS/WATBAL; demands from ground water and surface waters, demands for the major irrigated and nonirrigated land uses, and runoff from ground water irrigated lands, surface water irrigated lands and runoff from nonirrigated lands. The basic premise of this modeling effort is that fields having the same soil, climate, and land use have, a priori, the same hydrology. The hydrology of each land use is independent of every other land use, and therefore the runoffs or demands from each land use can be added together to produce a composite basin runoff or demand. Although this premise is not strictly true it allows a land use-based analysis of hydrology that would otherwise be impossible.

The simplicity of this model gives the water budget modeling approach several advantages. It can simulate hydrology over long (31 year) time periods. This allows prediction of daily demands, average demands, 1-in-10 maximum monthly demands, and so can make statistically meaningful estimates of 1-in-10 drought demands that can be compared with the District's Permit Allocation method and *Central and Southern Project Comprehensive Review Study* (Restudy) and *Lower East Coast (LEC) Regional Water Supply Plan* estimates. It can simulate the hydrology of a watershed that has continuously changing land uses. The model is relatively simple to calibrate. It can easily generate estimates of hydrology for any number of potential land use scenarios.

The water budget modeling has four separate components: AFSIRS, AFSIRS Water Budget, WATBAL, and Composite Flows and Stats. AFSIRS calculates irrigation requirements for cropland. The AFSIRS Water Budget spreadsheet was developed to calculate the runoff and ground water components for AFSIRS. The WATBAL spreadsheet calculates the water requirements for nonirrigated land. The model Composite Flows and Stats spreadsheet combines these runoffs and demands, reconciles the interactions between runoff and demands and calculates the net irrigation demand and runoff for each basin.

The watershed is composed of five drainage basins. For modeling purposes, these drainage basins can be divided into eight irrigation basins; six of which are modeled in this analysis. The six basins include the S-4 Basin (S-4), East Caloosahatchee-ground water

(ecal-gw), East Caloosahatchee-C43 irrigated (ecal-d), East Caloosahatchee-lake irrigated (ecal-lok), West Caloosahatchee-ground water irrigated (wcal-gw), and West Caloosahatchee-C43 irrigated (wcal-d) (**Figure L-1**).
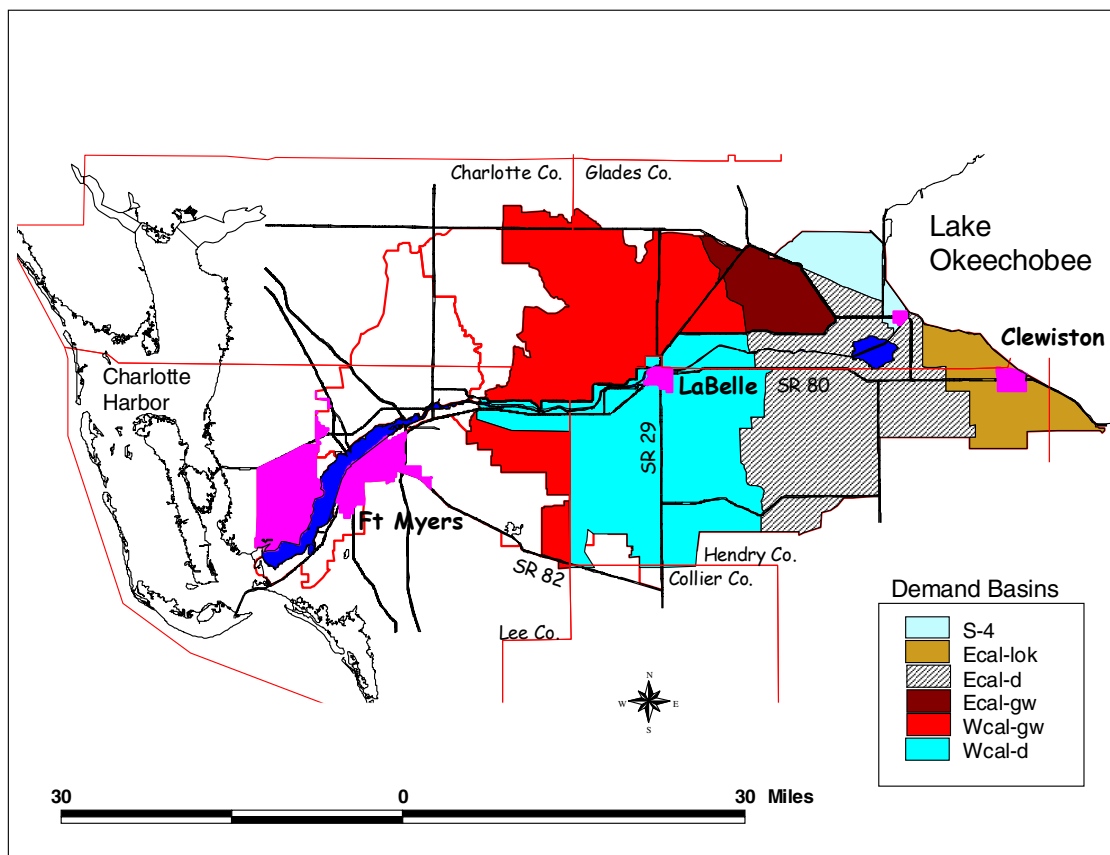
Figure L-1. Demand Basins of the Caloosahatchee Watershed.

This paper describes the AFSIRS model, general usage of the model, and the calibration of AFSIRS. The development and application of AFSIRS water budget and AFSIRS/WATBAL models are presented with a discussion of the overall application and calibration. Throughout this discussion, the hydrology of each land use is modeled using units of volume per unit area (i.e. inches of water) and converted into volume (i.e. acre-feet [ac-ft]) when determining basinwide runoff and demand.

AFSIRS MODEL

The AFSIRS model is a numerical simulation model, which allows the user to estimate irrigation requirements (IRR) for Florida crops, soils, irrigation systems, growing seasons, climate conditions and irrigation management practices. IRR for crop production is the amount of water, exclusive of precipitation, that must be applied to meet a crop's evapotranspiration (ET) requirements without significant reduction in yield. IRR, as

defined in this model, does not include leaching, freeze protection, or crop cooling requirements, even though water for these purposes may be applied through an irrigation system.

The AFSIRS model is based on a water budget of the crop root zone and the concept that crop ET can be estimated from potential evapotranspiration (ETp) and crop water use coefficients. The water budget approach was used to develop a Florida citrus micro irrigation scheduling model (Smajstrla et al., 1987). Smajstrla and Zazueta (1987, 1988) demonstrated the data requirements and sensitivity of the water budget approach to determining irrigation requirements of Florida nursery and agronomic crops. The water budget includes inputs to the crop root zone from rain and irrigation, and losses from the root zone by drainage and ET. The water storage capacity in the crop root zone is defined as the multiple of the water-holding capacity of the soil and the depth of the effective root zone for the crop being grown. This level of simulation model development produces a functional model that could address the wide variety of crops, soils, and irrigation systems typical of Florida.

The water budget approach to the simulation of IRR requires that the extent of the crop root zone be defined for each crop. This is determined as a function of the annual crop growth stage given as fractions of the crop-growing season. The crop root zone also is subdivided into irrigated and nonirrigated zones and separate water budgets are maintained for each zone. Depending upon the method of irrigation, it is common practice to irrigate only the upper portions of the crop root zone where most of the roots are located, rather than to irrigate the maximum depth to which any few individual roots penetrate. Also, for micro irrigation systems, only a portion of a fraction of the soil surface is normally irrigated with these systems. For other production systems such as those, which use seepage irrigation, the entire crop root zone is irrigated because of the manner in which water is applied. As the nonirrigated root zone dries during drought periods, water becomes less available in this zone, and a greater proportion is then extracted from the irrigated zone in order to meet the total crop ET. When the available water is entirely depleted from the nonirrigated root zone, all extractions are simulated to occur from the irrigated root zone.

Daily ET for each crop is calculated as the multiple of potential ET and the crop water use coefficient (Kc) for that day. The Kc values vary with the growth stage of the crop. Crop water use coefficients were obtained from the literature. Three separate sets of Kc values were examined in this study. Most Kc data were obtained from non-Florida research studies because relatively few studies have been conducted in Florida. No data were available to allow distinctions in Kc values to be made on the basis of management practices, such as the use of plastic mulch.

Irrigation is scheduled based on an allowable level of soil water depletion from the crop root zone. Irrigation amounts are optionally calculated to restore the soil water content to field capacity, to apply a fixed amount of water per irrigation, or to restore the soil water content to a given fraction of field capacity (deficit irrigation). Either net irrigation requirements, which consider only the crop water needs, or gross irrigation

requirements, which also considers the water application efficiency of the irrigation system being used, can be calculated.

Drainage is defined as that portion of rainfall in excess of rain stored in the soil profile to field capacity or extracted by ET as the water redistributed in the soil. If rainfall is less than the depth required to restore the crop root zone to field capacity, then all of the rainfall is effective, and drainage is zero. If rainfall exceeds the depth required to restore the soil water content in the crop root zone to field capacity, then effective rainfall was calculated as the difference between the current and maximum soil water contents. Drainage is the difference between rainfall and effective rainfall. No drainage was assumed to occur as a result of irrigation. Lateral flows are not considered in AFSIRS.

AFSIRS HISTORY

The Agricultural Field-Scale Irrigation Requirements Simulation model (AFSIRS) (Smajstrla, 1980) model was developed in the early 1980s in response for the need to predict irrigation requirements. The water management districts needed a reliable method to estimate potential water use. AFSIRS was developed under a join contract by the five water management districts in Florida to provide a method for estimation of estimating irrigation requirements for permitting agricultural water use.

The AFSIRS model has been used to some degree for water supply planning and water use permitting in each of the water management districts. AFSIRS is used for all agricultural water permits in Northwest Florida Water Management District. Although the values are thought to be somewhat higher than actual water use, the AFSIRS values are acceptable. The standard default values from the AFSIRS documentation are used in the model. The water supply planning group does not use the AFSIRS model for future water use estimation. The Suwanee River Water Management District does not use the AFSIRS model for evaluating agricultural irrigation requirements. They use estimated water use requirements for selected crops provided in the Florida Irrigation Guide. Although interested in AFSIRS, they have no pressing requirement to use the model.

The Southwest Florida Water Management District (SWFWMD) has reviewed AFSIRS for use in estimating agricultural water demands and concluded that the model is too difficult to use for their applications. They have found that the AFSIRS model is a complex application of a simple water budget model that requires considerable training and experience to be applied effectively. The model requires careful selection of rooting zone depths and water table location to provide accurate estimates of irrigation requirements. They also found that the soil water depletion rates that are used to determine irrigation frequency do not follow University of Florida recommendations and must be adjusted correctly to produce the correct irrigation behavior. The AFSIRS model does not accurately describe the soil wetting characteristics of low-volume irrigation methods. With the default values supplied with the model, AFSIRS tends to over predict irrigation requirements. Although accurate for planning purposes when used by an experienced agricultural engineer, it is not recommended for use in agricultural water use permitting because of the complexity of the model.

The AFSIRS model is used by the St. Johns River Water Management District (SJRWMD) to estimate consumptive use for most agricultural crops. The default values that are provided for each crop with the model are used to estimate irrigation requirements. For citrus, they have found that the AFSIRS model over predicts water use and they use a modified Blaney-Criddle model (B-C) for estimating irrigation requirement. For potato farming, they use empirical field data from their "Benchmark Farms" program to determine water use requirements. The benchmark farm data provide information on total water use whereas AFSIRS only considers ET losses and irrigation application efficiencies.

The AFSIRS model is not used in the water supply planning program at SJRWMD. The planning group uses the modified Blaney-Criddle model for estimating future water demands. They have found that the AFSIRS does not account for water use that results from ancillary activities such as crop establishment, irrigation system maintenance and other water uses. AFSIRS does not account for differences in system efficiencies resulting from farm management and irrigation system maintenance. The lack of climate data for AFSIRS is considered a significant problem. AFSIRS requires daily climate data or PET data. This data is only available from two locations in the water management district and that is not considered sufficient to use the model. For crops of critical concern to SJRWMD, the crop coefficients used to estimate actual ET from PET values are not sufficient to estimate total water use.

The results of the AFSIRS model have been compared to the modified B-C model to provide confidence in the B-C results. In selected test cases, the modified B-C model produced results that were close agreement with the AFSIRS model.

Currently, SJRWMD is conducting a review of the AFSIRS model. This review will be used to verify that the algorithms used in AFSIRS are appropriate and the best available information.

APPLICATION OF AFSIRS

AFSIRS was modified to estimate runoff as well as water use demands for individual fields based on the same soil, climate, land use and irrigation system. The original FORTRAN code was modified to provide improved runoff data and provide additional statistics for evaluating the irrigation demand and drainage.

AFSIRS was used to simulate the hydrology of the four primary land use types and irrigation systems used in the Caloosahatchee Watershed: citrus with traditional crown-flood irrigation, citrus with low-volume micro jet or drip irrigation, sugarcane with subsurface seepage irrigation, and a dual crop of spring and winter micro spray irrigated tomatoes. Irrigated pasture runoff and demands are actually those of crown-flood irrigated citrus. AFSIRS land uses that are equivalent to those defined in the *SFWMD Permit Information: Volume III Basis of Review for Water Use Permits* (SFWMD, 1992).

Soil characteristics were modeled as uniform throughout the watershed and were assumed to be equivalent to the '0.8 inch' soil as defined in Vol. III. The '0.8 inch' soil is used in almost all permits within the CWMP region. Although there are over 20 major soil series in the agricultural areas of the watershed, selecting a single soil type for agricultural land is a reasonable first estimate of soils used for agriculture. It may tend to under predict irrigation requirements for the more sandy soils that have a lower water holding capacity. Using additional soils in AFSIRS/WATBAL would be difficult because there is little field data available to verify and calibrate the model for those soils.

The only AFSIRS parameters that were varied in this study were the monthly crop correction coefficients (Kc) that are used to convert potential evapotranspiration (PET) to the potential crop specific evapotranspiration. All other AFSIRS parameters are the standard parameters provided by Smajstrla (1990) for selected irrigation methods and crop characteristics. The crop characteristics include the rooting depth and crop growth pattern. The soil characteristics used in this study were developed by March as being representative of the SFWMM '0.8 inch' soil. This is the dominant soil classification applied to the Caloosahatchee watershed.

Three sets of monthly crop correction coefficients were tested (**Figure L-2**). One set was the default crop correction coefficients developed for the AFSIRS model (Smajstrla, 1990). The second set was from the South Florida Water Management Model (SFWMM). These are both developed for Penman PET data and were used without further modification. The third set was derived from SFWMD Water Use permitting database for the Blaney-Criddle water use demand model (SFWMD, 1992). Because these were developed for Blaney-Criddle PET data, the coefficients were adjusted based on the ratio of average monthly Penman PET to Blaney-Criddle PET for LaBelle.

Initially, the AFSIRS crop correction coefficients were selected because they tended to predict demands for low rainfall months better than the other methods. However, the modeled demand calculated for citrus and sugar cane were unusually high compared to measured values volumes for sugarcane in the EAA and citrus in Indian River, the resulting runoff volumes from irrigated lands were unrealistically low. The modeled runoff was better described by AFSIRS using the SFWMM Kc values than with either the AFSIRS or Blaney-Criddle Kc values.

Complete records of daily rainfall for 1965-1995 were developed for each of the five demand basins using the Theissen polygon method on nine rainfall stations in the region (**Figure L-3**). Complete records of daily reference crop PET were developed for 1965-1995 for each of the five demand basins using the Theissen polygon method on the three evapotranspiration stations in the region.

AFSIRS WATER BUDGET MODEL

The AFSIRS Water Budget model was developed to provide a complete hydrologic model for irrigated land. Being a root zone model, AFSIRS does not simulate and saturated flow, surface water flow or open-channel flow processes. AFSIRS simulates
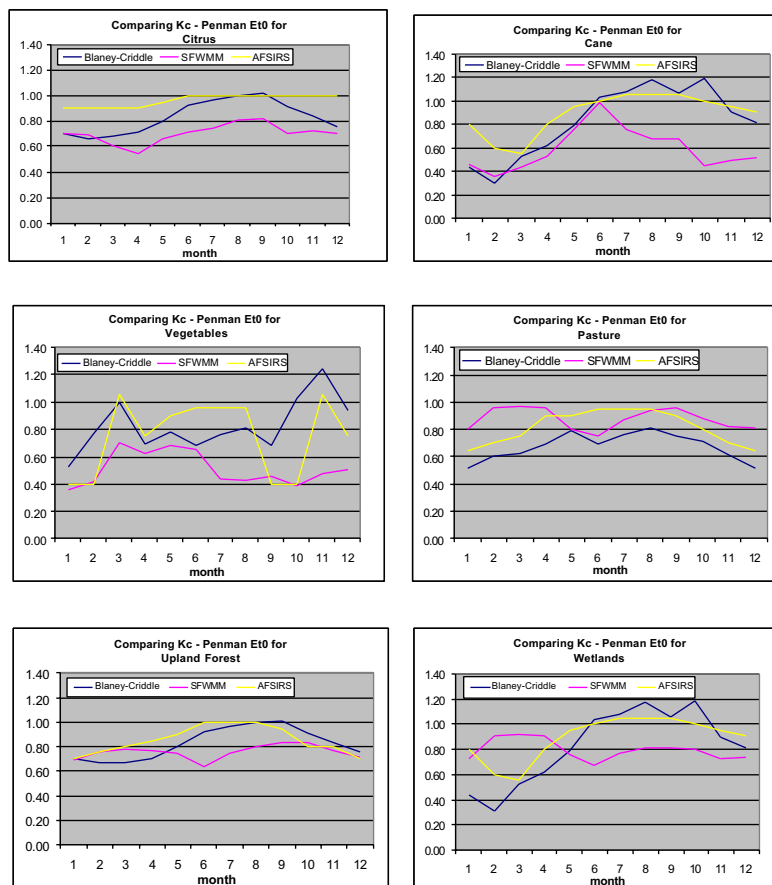
Figure L-2. Blaney-Criddle, AFSIRS, and SFWMM Crop Correction Coefficients for Primary Land Cover Types in the Caloosahatchee Watershed.

application losses but does not consider atmospheric or delivery losses from the irrigation system. The AFSIRS Water Budget model postprocesses AFSIRS field-scale runoffs and demands to produce basin-scale demands and runoff. For surface irrigated lands, this model has two parameters for irrigation: atmospheric irrigation efficiency (EFF1), local storage (STOR1), and the model has two parameters affecting the timing of runoff: drainage capacity (CAP1), and a runoff storage coefficient (COEFF1). All four parameters are estimated during the calibration process.

The irrigation efficiency term is a lumped calibration parameter that includes transmission losses, incidental irrigation, irrigation for management activities, and the atmospheric losses. It accounts for water pumpage by the various agricultural operations in the basin that are in excess crop requirements. The EFF1 term is the effective crop correction term applied at the basin scale. Demands are increased by dividing the field-scale demand by the atmospheric efficiency term.
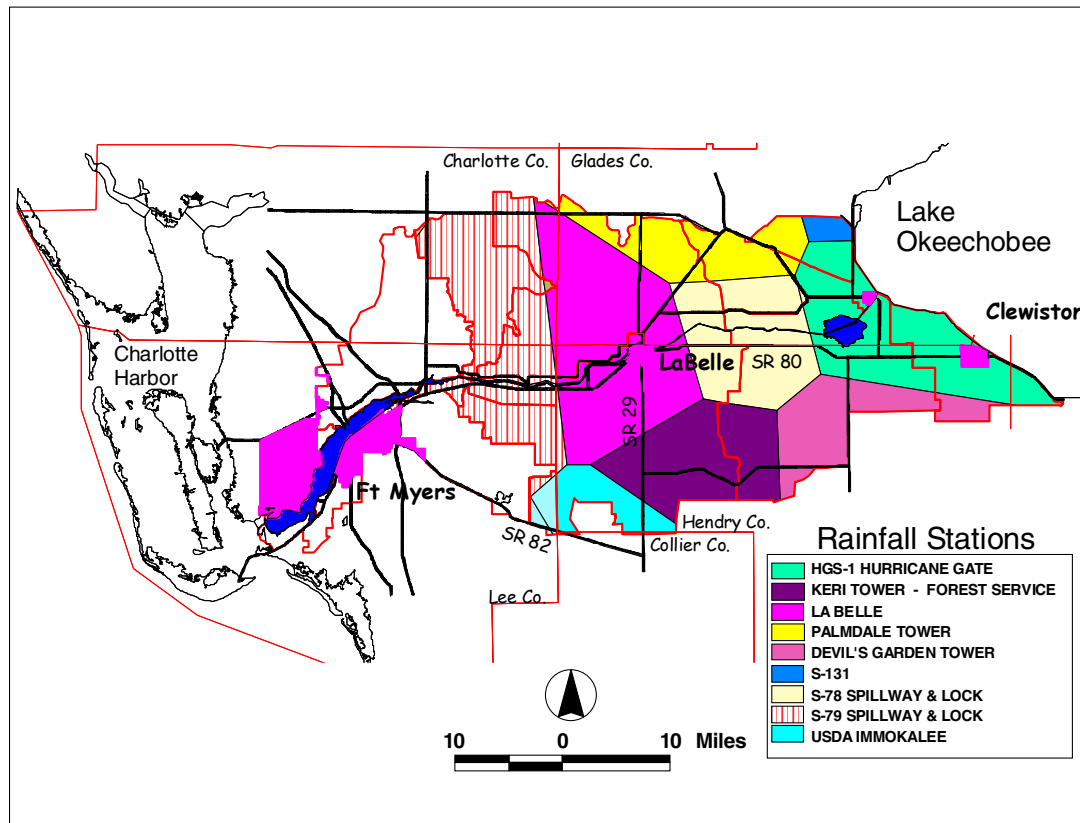
Figure L-3. Theissen Rainfall Polygons for the AFSIRS/WATBAL Model.

The local storage term is introduced to convert individual field-scale demands and runoffs into basin-scale demands and runoff. All field-scale demands are removed from local storage until the local storage is depleted. Field-scale runoff must replenish local storage before excess basin-scale runoff can occur. This term decreases both irrigation demands and runoff. The meaning of the term 'local storage' is deliberately vague. It could be errors in predicting rooting depths and could be replaced by calibrated AFSIRS values. However, the term also encompasses shallow ground water storage, upward water flux, which is not modeled in AFSIRS, and canal storage. Water in local storage is retrievable by the existing irrigation system.

Basin runoff is described by a simple linear-reservoir routing model applied to all field-scale runoff. The linear reservoir routing model has two parameters: a drainage capacity parameter that limits maximum runoff and a runoff storage coefficient that describes the rate at which a runoff volume is released. These terms decrease peak runoff rates and delay the entry of runoff into the stream.

When the AFSIRS Water Budget model is applied to lands irrigated from ground water sources, an additional process is needed to deplete and recharge ground water. For such cases, field-scale runoff recharges the aquifer at a maximum recharge rate defined by

the user. It was found that recharge rates greater than 0.4 inches per day gave identical results so a rate of 1 inch per day was used in all cases. Because AFSIRS simulates irrigation application inefficiencies, the excess irrigation water is used to recharge the ground water aquifer. This approach assumes a direct and rapid connection between the water table aquifer and the aquifer, which is used as a source for irrigation. Based on empirical data, this appears to be reasonable in the regions of the watershed where agriculture depends on ground water.

A second term was added to limit withdrawals from the aquifer. A maximum withdrawal volume of six inches was selected for all simulations. This volume was selected because it limits the withdrawal so that recovery occurs within one year. This approximates the informal definition of **no harm** currently used by the SFWMD. Because field-scale irrigation demands exceed 20 inches per year, lands that are ground water irrigated frequently cannot meet their own needs. These unmet demands are supplied from runoff from nonirrigated lands in the same demand basin. The two ground water irrigation parameters affect watershed hydrology by reducing runoff from basins that are supplied by ground water. Finally, a three-day moving average was used during the process of converting irrigation demands from inches into acre-feet. This approximates a three-day irrigation cycle.

WATBAL MODEL

Because AFSIRS only simulates hydrology for irrigated lands, a separate hydrologic model was created for nonirrigated lands. The WATBAL model calculates ET and runoff for wetlands, upland forest, and grassland or pasture. The grassland category contains all miscellaneous land uses. These are the primary land cover types in the Caloosahatchee Watershed. Each land use is modeled with a root zone component that is replenished by rainfall and depleted by evapotranspiration. As with AFSIRS, monthly crop correction coefficients, are used to convert PET to the crop specific evapotranspiration. When the root zone is empty, evaporation becomes zero and when it is overfull runoff occurs. Runoff is routed using the same linear routing method used in the AFSIRS Water Budget model.

COMPOSITE FLOWS AND STATS MODEL

The Excel spreadsheet Composite Flows and Stats combines these runoffs and demands and considers interactions between runoff and demands for each of the five demand basins in the study area. Effects of neighboring lands, distance from the irrigation source, and water control practices are assumed to be negligible. The interactions between the hydrology of each land use are limited and occur as follows. First, flows from the nonirrigated lands in the two ground water demand basins are used to supply unmet ground water demands. Second, days with simultaneous C-43 Canal demands and runoff within in the East Caloosahatchee Drainage Basin are resolved so that the day has either demand or runoff. This reduces both runoff and demands. Third, days with simultaneous C-43 Canal demands and runoff within in the West Caloosahatchee Drainage Basin are

resolved so that the day has either demand or runoff. Hydrologic summaries and comparative statistics are also made in this model. The AFSIRS and WATBAL models simulate hydrology in units of inches per day that are converted to units of acre-feet using land use over time lookup tables.

The overall AFSIRS/WATBAL model consists of the AFSIRS FORTRAN model and 12 Excel spreadsheets. There is an AFSIRS water budget spreadsheet and a WATBAL spreadsheet for each of the five demand basins. The Composite Flows and Stats spreadsheet contains the combined data from all spreadsheets and the Summary data and Stats spreadsheet contains the final statistics for the combined watershed model.
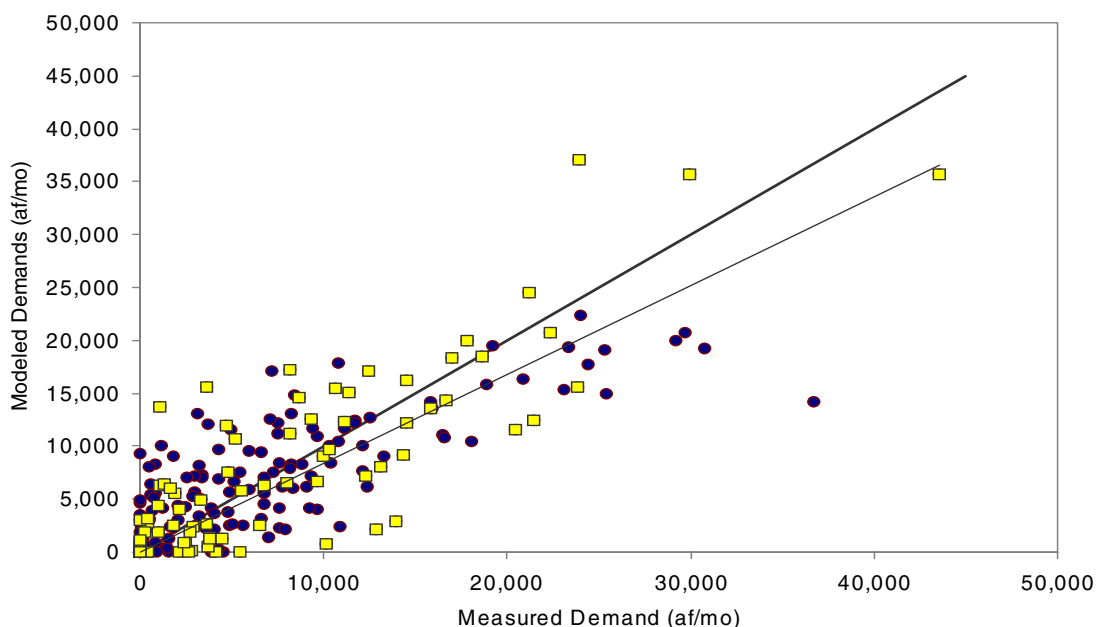
CALIBRATION

The AFSIRS/WATBAL model was calibrated using an iterative process that has several steps. Calibration consisted of defining two global irrigation parameters, and five parameters for three types of nonirrigated lands (a total of seventeen parameters). The data available for calibrating the model was limited to the flow data measured at three locations in the watershed. These basin-scale measures were used to calibrate the field-scale and basin-scale parameters. The strategy for calibration was to select reasonable values for each parameter, run the model, and evaluate the results using several goodness-of-fit (GOF) measures. The GOFs were used to compare the simulated demand and runoff to the measured flows. The model parameters were adjusted to obtain the best GOFs.

The measured data for demands were based on measured flow data from 1972 through 1995 at the S-77, S-78, and S-79 lock and dam structures. Regulatory releases, Public Water Supply (PWS) withdrawal, and water quality releases were processed out of the data. The residual flows were separated, by day, into a set of negative values and positive values. The set of negative values is basin demands where inflow from Lake Okeechobee exceeds outflows at S-79. The set of positive values is watershed runoff values. The calibration period was from Jan 1, 1988 through Dec 31, 1995.

The first step in the calibration process was to run all AFSIRS models using an appropriate set of crop correction coefficients (the South Florida Water Management Model coefficients were eventually found to provide the best overall fit). The second step was to roughly calibrate the nonirrigated land parameters by comparing modeled to measured runoff from the combined East and West basins. The third step was to calibrate the AFSIRS irrigation parameters by comparing modeled to measured demands from Lake Okeechobee. Then steps two and three were repeated until both runoff and demand estimates were optimal.

The goodness-of-fit (GOF) characteristics for demands were based on monthly demands. The GOF were: 1) the error in average annual demands, 2) the slope of modeled monthly demand versus measured monthly demand, and 3) the Pearson correlation coefficient of modeled versus measured monthly demands. The most understandable evaluation of the model is a comparison of measured and modeled monthly demands plotted over time. The slope of the modeled- measured (**Figure L-4**) and the monthly

Pearson correlation coefficient (**Table L-1**) provide a measure the goodness of fit of the modeled to measured demand. The Pearson correlation coefficient indicates there is a good correlation. The calibration is stopped when the highest values are obtained. This visual comparison shows that the model is reasonably good at predicting monthly demands from the C-43 Canal. The regression coefficient is low indicating a lot of spread in the data.

Figure L-4. Modeled versus Measured Monthly Irrigation Demand from C-43 Canal for the East and West Caloosahatchee Basins (Calibration Period Shown As Squares).

Table L-1. Goodness of Fit (GOF) Values for Calibrating Measured and Modeled C-43 Canal Demands for the East and West Caloosahatchee Basins.

	1988-1995 Calibration Period		1972-1995 Total Period of Record	
	Measured	**Modeled**	**Measured**	**Modeled**
Irrigation (acre -feet per year)	77,465	78,214	65,600	78,700
Slope of Modeled to Measured Monthly Demands		0.841		0.949
Monthly Pearson GOF		0.860		0.822

The calibrated values for irrigation efficiency and local storage are presented in **Table L-2**. The low values for EFF1 indicate that there is a lot of water use not directly related to crop irrigation requirements. The low EFF1 values increase irrigation demands. This extra demand ends up in the atmosphere but the processes are not modeled. Efficiency this low is possible especially if transmission losses are great. The local storage term (STOR1) is approximately 0.05 inches which represents a small degree of water table variation.

Table L-2. Calibrated Values for AFSIRS Water Budget Model.

Irrigation efficiency1 (consumptive use by plant / amount lost to air)	EFF1	58%
Local Storage Depth (inches)	STOR1	0.05
Drainage capacity (inches/day)	CAP1	7.00
Storage coefficient (day)	COEF1	7.00

The model was calibrated to data from the period 1988-1995. The resulting modeling was evaluated for the period 1972-1995. The final calibrated values are presented in **Table L-3**. The hydrologic characteristics for the nonirrigated land are provided in **Table L-4**.

**Table L-3.** Calibrated Values for WATBAL Model Parameters.

	Rangeland	Upland Forest	Wetlands
Plant available water (PAW) capacity (inches)	1.40	4.80	5.00
Drainable storage capacity (inches) [CAP1]	7.00	7.00	1.00
Storage coefficient (days) [COEF1]	7	9	8
Total ground water storage (inches)	7.00	7.00	5.00
Root zone depth (inches)	20.0	68.6	12.5

Table L-4. Hydrologic Characteristics of Nonirrigated Land Based on Calibration of the WATBAL-Ecalc Model for the Period 1972-1995.

	Rangeland	Upland Forest	Wetlands
PET*K (inches/year)	49.5	42.7	44.6
AET (inches/year)	35.9	37.6	38.6
Drainage (inches/year)	14.1	12.3	11.2
Flooding (inches/year)	1.79	5.37	14.9

Several GOF metrics were used to evaluate the runoff calibration (**Table L-5**). The GOF characteristics used for runoff were always based on moving 5-day average runoff. The measure runoff was compared to the modeled runoff for the calibration period and the

validation period. The model over predicts runoff during the calibration period by 5 percent and under-predicts runoff during the validation period by 4 percent. The regression coefficient and the Pearson correlation coefficient are both high indicating a good comparison between the modeled and measured data. However, there are many low values that obscure the fit of the data (**Figure L-5**).


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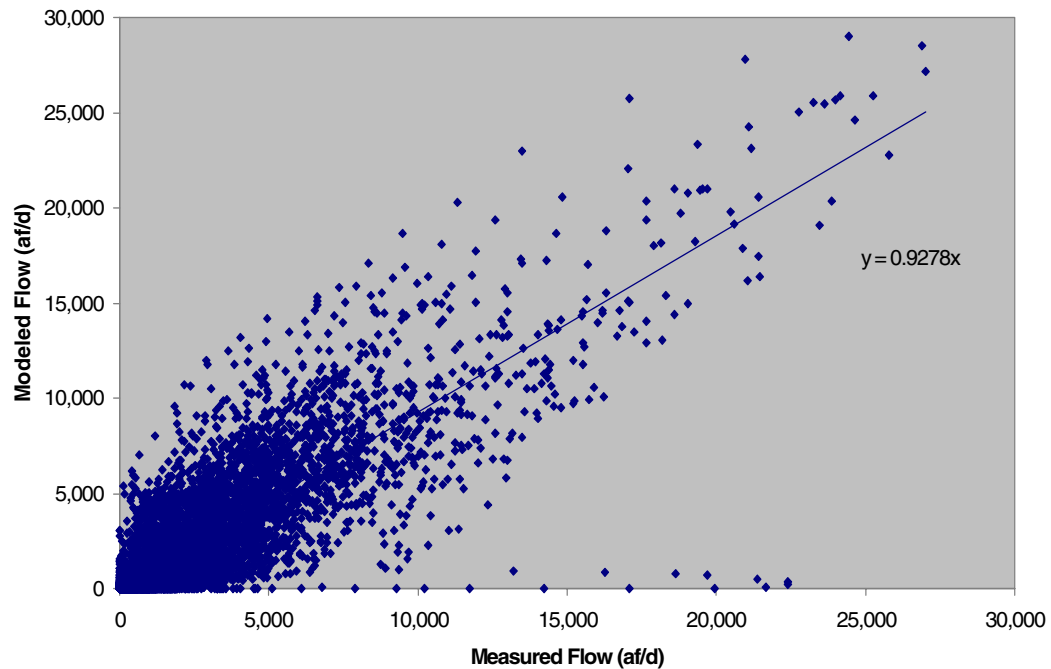
Figure L-5. Five-Day Average Modeled Runoff Compared to Measured Runoff for Ecal Basin As Part of the Calibration Process.

Table L-5. Measures of Goodness of Fit for Calibration of WATBAL-Ecal Model.

	1988-1995	1972-1995
	(1,000 ac-ft/yr)	
Runoff - Modeled	769	673
Runoff - Measured	754	704
Goodness of Fit		
Model-Measured Error (ac-ft/y)	37	-26
Runoff (Model)- Runoff (Measured) / Runoff (Model)	4.93%	-3.62%
Slope of Modeled - Measured Runoff	1.042	0.913
Regression Coefficient of Modeled - Measured Runoff	0.803	0.724
Pearson Correlation Coefficient	0.896	0.851

With the calibrated model parameters, the AFSIRS Water Budget models for the ground water demand basins and the Lake Okeechobee Basin were used to calculate basin demand and runoff. These values were used in the WATBAL models to estimate basin runoff that includes runoff from nonirrigated land. The results from all AFSIRS/ WATBAL basin models were combined to evaluate the demand and runoff for the entire watershed.

The model is not particularly good at explaining high demand months (**Figure L-6**). It is believed that this is due to operator controlled management decisions - which are not modeled. The problem seems to be that operator decisions influence the timing of C-43 Canal withdrawals. Management decisions seem to have the ability to over utilize or under utilize irrigation waters by about 1 inch of irrigation over the irrigated area.
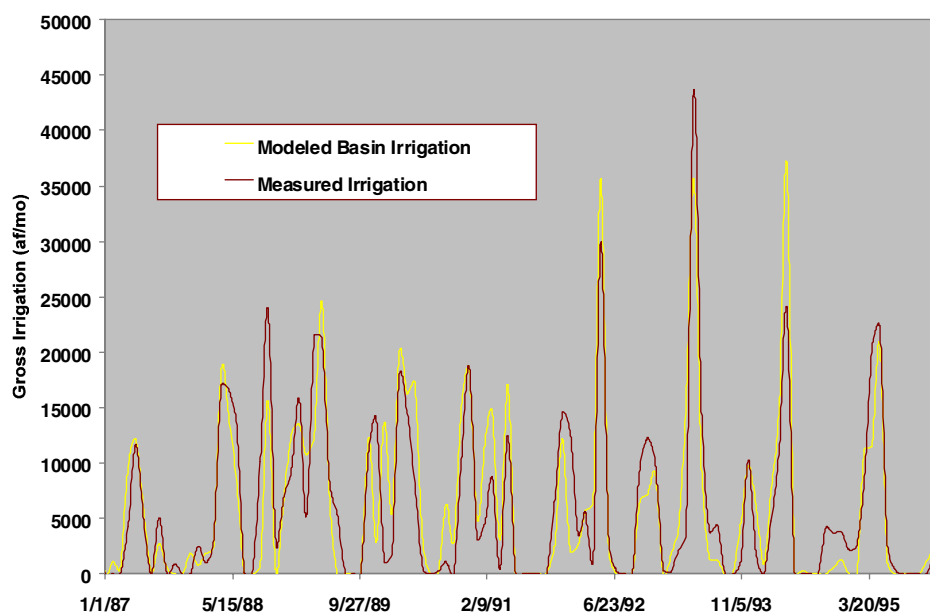
Figure L-6. Modeled and Measured Irrigation Demand for the Caloosahatchee Watershed.

The model predicts hydrology over the full period of record (**Figure L-7**). However, there is a tendency to underpredict large runoff events during the early years. This may be due to poor estimates of land use during this period. The modified AFSIRS simulations had the least tendency to underpredict large runoff events during the early years.

The AFSIRS/WATBAL model is built using field-scale parameters to model watershed-scale hydrology. The field-scale estimates of demand and runoff were compared to the basin-scale results (**Table L-6**). There was little difference between the runoff between the basin-scale and watershed-scale. Runoff is produced primarily by
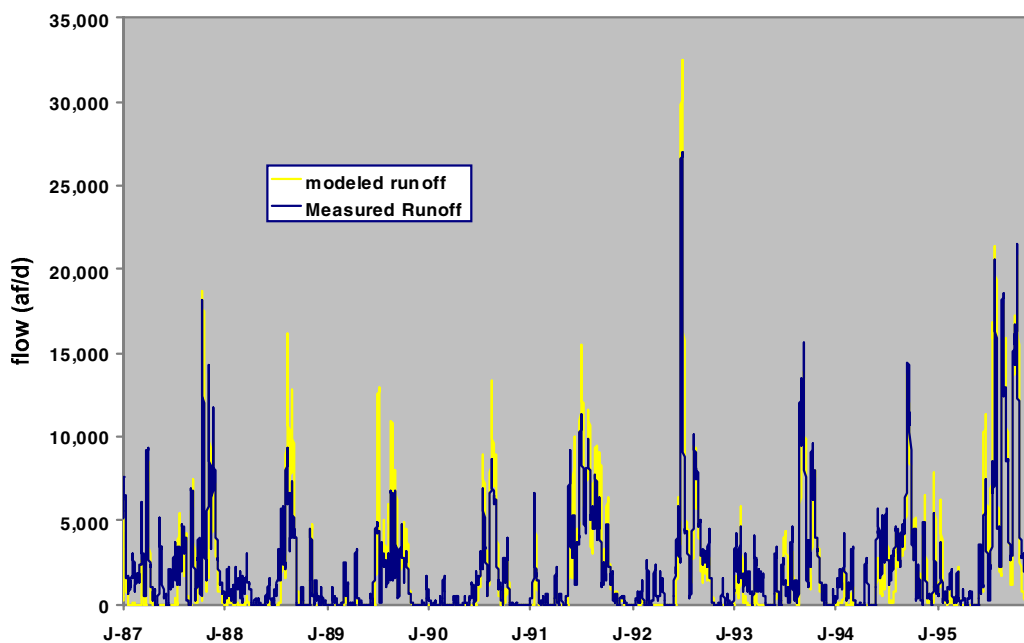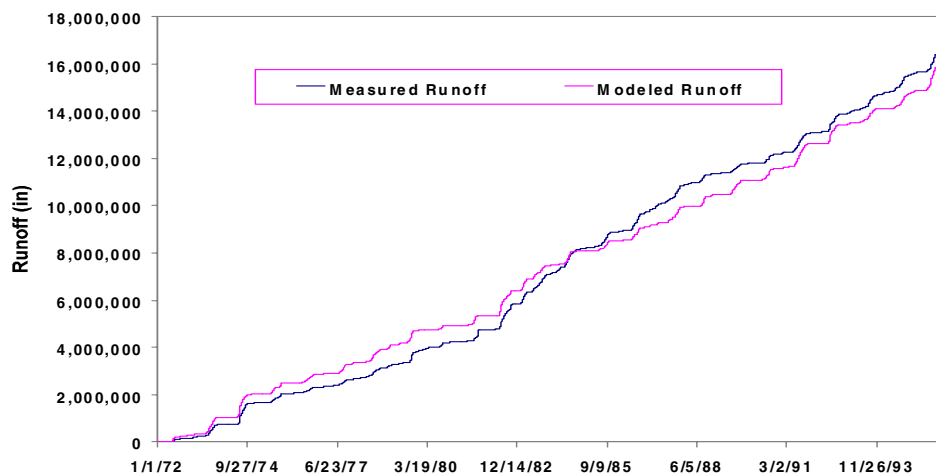
Figure L-7. Modeled and Measured Flow for the Caloosahatchee Watershed.

large rainfall events that have little interaction with the watershed. There should not be a large difference the basin-scale runoff and the watershed-scale runoff. There is a larger difference between the basin-scale demands and the watershed-scale demands. Runoff within an irrigation demand basin reduces demand and recharges local storage and there will be less watershed-scale demand than the basin-scale demand. The difference between the values for the East Caloosahatchee Basin is because the parameters were calibrated using these data. The watershed demand is similar to the irrigation basin demands. The agricultural demands are not met by runoff from other demand basins.

Table L-6. Comparison of Runoff and Demand for Demand Basins and the Combined Watershed.

	Irrigation Basin-Scale	Watershed-Scale	
	(1,000 ac-ft/yr)	(1,000 ac-ft/yr)	Scale Effect
Runoff			
East Caloosahatchee	286	282	2%
West Caloosahatchee	427	422	1%
East and West Caloosahatchee	714	701	2%
Demands			
East Caloosahatchee Agricultural	49	44	9%
West Caloosahatchee Agricultural	30	25	18%
East and West Caloosahatchee - Total	79	66	16%

The cumulative runoff for the watershed is another measure of the reliability of the AFSIRS/WATBAL model (**Figure L-8**). The modeled and measured runoff follow the same pattern for the period of record. Initially the model over-predicts runoff, which is probably due to inaccurate land use data in the early part of the period. The model under-predicts during the later period due to the inability to accurately simulate the effect of the canal system on drainage.

Figure L-8. Cumulative Measured and Modeled Runoff for the Caloosahatchee Watershed.

Land Use During Calibration

There has been a substantial increase in irrigated lands within the Caloosahatchee over the calibration period. AFSIRS/WATBAL modeling is able to simulate the changes in irrigation demands and runoff that result from changing land uses. For calibration, historic land use-over-time tables were developed for each irrigation basin. District land use coverages were used to establish 1988 and 1995 land use. The 1972 land use was developed from earlier District studies. Landuse for intermediate years were interpolated based on historic countywide crop land use data published by Florida Agricultural Statistics Service (FASS). The ratio of crown-flood irrigated citrus and micro jet irrigated citrus and the ratio of irrigated pasture and nonirrigated pasture were developed from anecdotal information.

APPLICATION

Model Application - 1995 and 2020 BASE Demands

The results of AFSIRS/WATBAL are an acceptable first estimate of demands in the Caloosahatchee watershed for 1995 and 2020 base modeling. The method used is

based on engineering principles and is responsive to land use, irrigation method and water source. The responsiveness to various water sources is the critical concern for the CWMP. The method accounts for public water supply requirements, which is good. The method agrees acceptably with measured data. The simulated irrigation requirements and drainage are compatible with values from other regions of the district for similar land uses. However, the low efficiency suggests that return flows and application efficiencies are significant processes that should be modeled using deterministic methods. The model is calibrated to a limited amount of data, flow at three structures.

The base cases for 1995 and 2020 are modeled assuming unchanging land use for thirty-one year simulation period. The thirty-one years are needed to show how the watershed may respond to a wide variety of climates. The 1995-land use acreage comes from the District's 1995 land use coverage. The estimated 2020-land use acreage for irrigated agriculture was developed by the CWMP. A large increase in acreage of sugarcane and citrus is expected. The spatial distribution of citrus and sugarcane assumes no expansion of the Lake Okeechobee Service Area (LOSA) but it does allow assume all development of undeveloped lands in LOSA would rely on C-43 Canal waters. The increase in irrigated agriculture results in a decrease in pasture and some wetlands.

The AFSIRS/WATBAL model predictions for the 1995 BASE demands and runoff from the C-43 Canal are presented in **Table L-7**. The annual runoff is 17 percent less than the current SFWMM model estimates but is closer to measured runoff than the SFWMM estimates. The annual demand is 24 percent greater than the current SFWMM estimates (89,500 ac-ft); the annual 1-in-10 demand is 26 percent greater than current SFWMM estimates (137,000 ac-ft); the May 1-in-10 demand is the same as current SFWMM estimates (42,600 ac-ft). The increase in demands and decrease in runoff are due principally to differences in the early simulation years - 1965 to 1980. Demands predicted by the new AFSIRS-based hydrology are linearly proportional to agricultural acreage being irrigated. Previous estimates of demands were derived with less reliable estimates of the agricultural acreage irrigated by the C-43 Canal. The watershed-scale runoff and demands are less than the basin-scale values because at the watershed scale some the demand from each basin is met by the runoff from the other basin. This is more important for the West Basin than for the East Basin. The demand by water source is given for each basin in **Table L-8**.

The estimated 2020 BASE demands from the C-43 Canal have an annual average of 183,800 ac-ft, an annual 1-in-10 demand of 285,300 ac-ft and a May 1-in-10 demand of 74,700 ac-ft (**Table L-9**). The annual demand is 64 percent greater than current SFWMM estimates (111,900 ac-ft); the annual 1-in-10 demand is 66 percent greater than current SFWMM estimates (171,600 ac-ft); and the May 1-in-10 demand is 40 percent greater than current SFWMM estimates (53,300 ac-ft). As in the 1995 BASE, twenty-five percent of these changes are due to higher demands in early simulation years. The remaining differences are due to the greater acreage of sugarcane (125,000 ac) and citrus (125,000 ac) assumed in the revised estimates as compared to the early *LEC Regional Water Supply Plan* estimates (99,700 ac of sugarcane and 116,000 ac of citrus). The demand by water source is given for each basin in **Table L-10**.

Table L-7. Estimated 1995 Demands from C-43 Canal Surface Water.

	1995 Base: AFSIRS/WATBAL		1995 Base: SFWMM
	Basin-Scale	Watershed-Scale	Watershed-Scale
	(1,000 ac-ft / yr)		
Runoff			
East Caloosahatchee	291	286	
West Caloosahatchee	405	393	
East and West Combined	696	675	815
Demands			
East Caloosahatchee Agricultural	76	70	
West Caloosahatchee Agricultural	46.5	40	
West Caloosahatchee public water supply	11.5	5	
East and West Combined	134	112	89.5

Table L-8. Estimated Average Annual Demands for 1995 Land Cover for 31 Years of Climatic Data.

	Ground Water	Lake Okeechobee	C-43 Canal	Total Demand
	(1,000 ac-ft / yr)			
East Caloosahatchee	0.65	8.7	64.6	74.0
West Caloosahatchee	35.5	0	46.5	81.9
S-4	0	69.4	0	69.4
Public Water Supply	0	0	11.5	
Total	36.1	78.0	122	237

Table L-9. Estimates of 2020 Base Demands in Lake Okeechobee Service Area.

	2020 Base: AFS/WATBAL		2050 Base: SFWMM
	Basin-Scale	Watershed-Scale	Watershed-Scale
	(1,000 ac-ft/yr)		
Runoff			
East Caloosahatchee	305	292	
West Caloosahatchee	400	386	
East and West Caloosahatchee	705	672	815
Demands			
East Caloosahatchee Agriculture	146	134	
West Caloosahatchee Agriculture	61.7	55.6	
West Caloosahatchee Public Water Supply	17.7	9.0	
East and West Caloosahatchee	226	192	125

Table L-10. Estimated Average Annual Demands for 1995 Land Cover for 31 Years of Climatic Data.

	Ground Water	Lake Okeechobee	C-43 Canal	Total Demand
	(1,000 ac-ft/yr)			
East Caloosahatchee	3.4	6.2	129	138
West Caloosahatchee	33.7	0	61.7	96
S-4 Basin	0	70.7	0	71
Public Water Supply	0	0	17.7	18
Total	37	77	209	323

LIMITATIONS

The modeling does not perfectly match observed watershed behavior. Two weaknesses are observed; under prediction of runoff during moderate rainfall periods and under prediction of demands during very low rainfall periods. The runoff predictions might be improved by developing a more sophisticated runoff component that could simulate water movement and storage in canals. Uncertainty in runoff estimation is also due to sparse rainfall data. A large fraction of the rainfall occurs as small high intensity storms. The historic and current rainfall network does not provide sufficient data to support detailed hydrologic modeling. Improving the under prediction of demands during high demand months would require a different model - one that predicts conveyance losses explicitly instead of assuming that conveyance losses are proportional to irrigation demands. It is also possible that the crop correction factors are not accurate for high demand months. There is additional uncertainty due to the limited PET data. The 12 monthly crop correction coefficients and the atmospheric losses are parameters that are intimately connected with the variable PET data. The parameters must be matched to the PET.

Other factors contribute to modeling uncertainty. The assumption of uniform (noncalibrated) hydrologic properties throughout the watershed increases uncertaintyThe necessary assumption of uniform (calibrated) conveyance efficiency and local basin storage parameters throughout the watershed and across all irrigation methods may not accurately reflect all field conditions. These parameters known to vary spatially but this variability is not represented in a lumped model such as AFSIRS/WATBAL. Other factors include an oversimplified conveyance efficiency term, poor land use data, single soil type, and basinwide model parameters. The conclusions are dependent on accurate land use information and, more importantly, determination of the proper irrigation source(s) fore each land use. Knowledge of land use in early years is lacking and estimates may not be accurate; this may be responsible for poorer fit in early years.

Irrigation from ground water sources were modeled as being identical to irrigation from surface water sources, using the same AFSIRS data and the same efficiencies and local storage parameters. No further calibration was possible. Runoff from these lands was reduced as ground water withdrawals were replaced. The current ground water

component allows rapid recharge and extraction or irrigation water from the aquifer. This reduces surface water demands and peak runoff. The reduction in runoff caused by ground water irrigation is very significant and should not be ignored. This level of connection between runoff and ground water recharge may not reflect the connectivity throughout the watershed.

There is an uncertainty of about 1 inch in irrigation demands during high irrigation months. This uncertainty may be influenced by landowner management, which is not modeled. Better resolution should not be expected unless conveyance losses and in-stream water level control methods are simulated. It is reasonable to assume that this is due in part to lower conveyance efficiency during droughts and in part to landowner management.

CONCLUSIONS

The AFSIRS/WATBAL model provides a reasonable approach for estimating the demands of the Caloosahatchee Watershed for the current and future conditions. The model is based on the AFSIRS model which is an excellent though data intensive model to use for estimating crop irrigation requirements. The AFSIRS model provides the statistical distribution of demand for a 31-year climatic record, which is necessary to evaluate the long-term impact of land use changes. The AFSIRS model was modified to account for the hydrology of nonirrigated land and the interaction of ground water with surface water. The model was successfully calibrated to the measured demands and runoff of the East Caloosahatchee Basin, and the calibrated model was validated using demand and runoff from the West Caloosahatchee Basin. Although the model is limited by availability of field data to verify the field-scale demands and ground water-surface water interaction, it is useful for estimating demand and runoff at the basin-scale. The model accounts for changes in demands and runoff due to varying weather and land use. Although not varied in this application, the model also can account for the variability in irrigation methods and soil types. The model was successfully used to provide reasonable estimates of 1995 base demand and runoff and the demand and runoff for the 2020 base case land use.

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Appendix M
WATER USE AND RUNOFF IN THE CALOOSAHATCHEE BASIN

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ABSTRACT

The volume and timing of discharge from the Caloosahatchee River Basin has a major impact on the health of the Caloosahatchee Estuary in southern Charlotte Harbor. The Caloosahatchee Estuary receives runoff from four sources: the Caloosahatchee River Basin, the Everglades Agricultural Area (EAA), Lake Okeechobee, and the basin draining directly to the estuary. When Lake Okeechobee stage is high, water is released for flood protection, which may produce high discharge during the spring dry season. Although regulatory discharge from Lake Okeechobee can be greater than basin runoff, runoff from the river basin is the primary source of flow. Discharge to the Caloosahatchee Estuary has changed during the last fifty years, primarily as a result of construction of the C-43 Canal that provided for navigation, drainage and flood control, and facilitated agriculture and urban growth. Urban development and agriculture have increased water consumption and resulted in an additional requirement for flood protection. Increased flood protection has reduced the ground water recharge and available ground water. In the dry season, irrigation demand has been met by water released from Lake Okeechobee, however, the availability of lake water for the Caloosahatchee Service Area is likely to be limited in the future as water is required to satisfy water supply requirements of the lower east coast and the environmental needs of Lake Okeechobee and the Everglades. In the future, innovative means of managing water in the basin will be necessary to sustain growth in the region and protect the estuary.

INTRODUCTION

The Caloosahatchee Basin occupies the southern extent of the Charlotte Harbor Estuary Basin. This is a region of expanding urban and agricultural development with increasing demands on the water resources, both for water use and for flood protection. At the same time, there has been increasing concern for protecting the environment. A primary environmental concern is the requirement of reasonable freshwater discharge to the estuary; minimum flow of fresh water to the estuary to prevent excessively high salinity and reduction in high flows that reduce salinity to very low levels. Another environmental concern is protection of wetlands from excessive ground water drawdown due to drainage and pumping from ground water for irrigation. A first step in understanding water allocation issues is the development of a water budget for the basin.

This paper describes the important features of the basin, the water budget for the estuary from the basin, and the potential impact of future land use on the discharge to the estuary.

THE CALOOSAHATCHEE BASIN

The Caloosahatchee Basin forms a shallow trough 36 kilometers (km) wide and 110 km long that drains from Lake Okeechobee to the Gulf of Mexico. The longitudinal profile of the river exhibits a gradual drop of 6 meters (m) NGVD at the lake with most of elevation loss below old Lake Flirt (**Figure M-1**). The land slopes from a high of 23 m elevation from the north side to the river and from 13 m elevation on the south to the river. Formed under a marine environment, most of the shallow geologic materials are limestone, marls, silts, clays, shell, sand, and gravel and mixtures of these. Limestone is near the surface west of LaBelle and occurs as outcrops along an east-west line south of LaBelle. The soils are a mix of sandy spodosols throughout most of the basin with loams found west of LaBelle. Soils in the EAA, on the far eastern end of the basin are primarily muck.
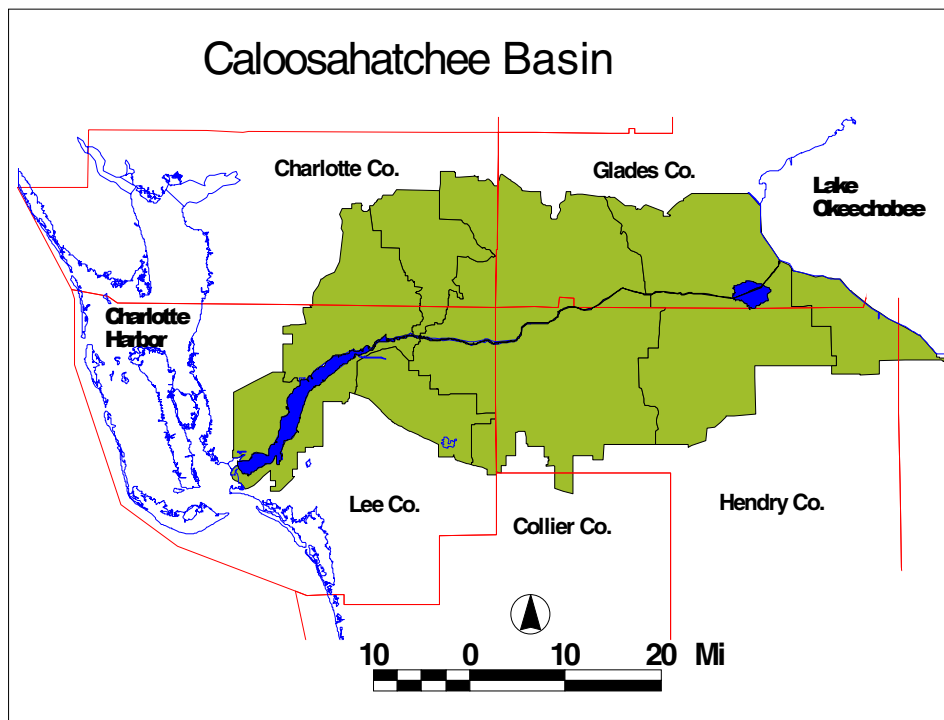
Figure M-1. The Caloosahatchee Basin.

The climate of the region is wet subtropical with 75 percent of the precipitation occurring during the summer wet season. The basin receives approximately 130 cm of rain annually (**Table M-1**). Annual rainfall ranges from 60 to 200 centimeters (cm) (SFWMD, 1994). There is slightly greater annual rainfall volume along the coast than inland, but this difference is not substantial compared to the high year-to-year variability. There is a high spatial variability in daily rainfall due to the localized nature of

convectional storms. There is a slight, but not significant increasing trend in rainfall of 0.15 cm yr-[1] over the period 1972 to 1994.

Table M-1. Annual Rainfall, Runoff and Water Use Demand in the Caloosahatchee Basin[a].

	Median	**2-in-10 Dry**	**2-in-10 Wet**
Rain (cm)	120	95	140
Lake Okeechobee			
Regulatory (10^6m^3)	69	3	830
Water Supply (10^6m^3)	94	66	124
Basin			
S-78 Discharge (10^6m^3)	350	225	475
ECAL Basin Runoff (cm)	36	21	46
S-79 Discharge (10^6m^3)	870	500	1,050
WCAL Basin Runoff (cm)	38	22	45
Water Use Demand			
Urban			
1990 Estimation (10^6m^3)		17	
2010 Projection (10^6m^3)		33	
Agriculture			
1990 Estimation (10^6m^3)		76	
2010 Projection (10^6m^3)		110	
Estuary			
Minimum Flow (10^6m^3)		270	

a. The period of record was 1972 to 1994. Rainfall and discharge were obtained from South Florida Water Management DBHYDRO Database. Water use demand estimates were obtained from the Lower West Coast Water Supply Plan (SFWMD, 1994c).

The ground water resources in the basin are limited. The basin is underlain by the Surficial Aquifer System (SAS), the sandstone aquifer, and the Floridan Aquifer System (FAS). The SAS, includes the water table aquifer (0-25 m) and the lower Tamiami formation (6-60 m), provides useable water in the region east of LaBelle. These aquifers can be highly productive, however, the yield is highly variable spatially, and it is not a dependable source of water for agriculture (Smith and Adams, 1988). West of LaBelle, ground water is too mineralized for agricultural use (SFWMD, 1994c). Several major municipal well fields in Lee County draw water from the sandstone aquifer. Urban wells

along the coast obtain water from the Floridan, however, this ground water is highly mineralized and requires reverse osmosis for use.

HISTORY

The hydrology of the Caloosahatchee Basin has been strongly affected by land and canal development. In predevelopment times, the Caloosahatchee River was a sinuous river extending from Beautiful Island to Lake Flirt. East of Lake Flirt was sawgrass marsh extending to Lake Okeechobee. The Caloosahatchee River was connected to Lake Okeechobee early in the 1800s by a small canoe trail by native Americans. In the 1880s, the Disston Canal was dug from Lake Flirt to Lake Okeechobee to provide a navigable channel for steamboats from Lake Kissimmee through Lake Okeechobee to the Gulf of Mexico (USACE, 1957). The channel was enlarged to a 2 m depth and a 30 m width during the period 1910 to 1930, and three locks were constructed along the canal in 1918 to improve navigation.

By the 1930s, there was pressure for drainage projects that would allow land development in the basin. Analysis of flood control showed that there was good drainage downstream of Hendry County but insufficient drainage east of LaBelle (Hills, 1927). The landscape was too flat and the river channel provided little conveyance capacity resulting in prolonged inundation. For example, floods in the 1920s left water 2 m deep in LaBelle. Hills (1927) recommended that a long, low dam be created near Ortona to divert runoff towards the Everglades and relieve flooding. Moore Haven and Ortona locks were completed in 1937, and the canal was straightened and deepened in 1937, 1941, and 1966 (Fan and Burgess, 1983). Severe floods in 1948, 1949, and 1953 resulted in construction of the current canal (USACE, 1957). The current channel was created to carry a maximum discharge of 120 (m^3s^{-1}) from Lake Okeechobee. The channel, C-43, was designed to remove runoff to reduce prolonged inundation, accommodate regulatory discharges from Lake Okeechobee, and provide a navigable channel. The project was completed in 1966 with the Franklin Lock and Dam Structure (S-79), which was designed to control water by reducing saltwater intrusion into the main channel, provide a freshwater head to reduce saltwater intrusion into the water table aquifer, and to maintain a higher water table in the lower region of the basin (USACE, 1957).
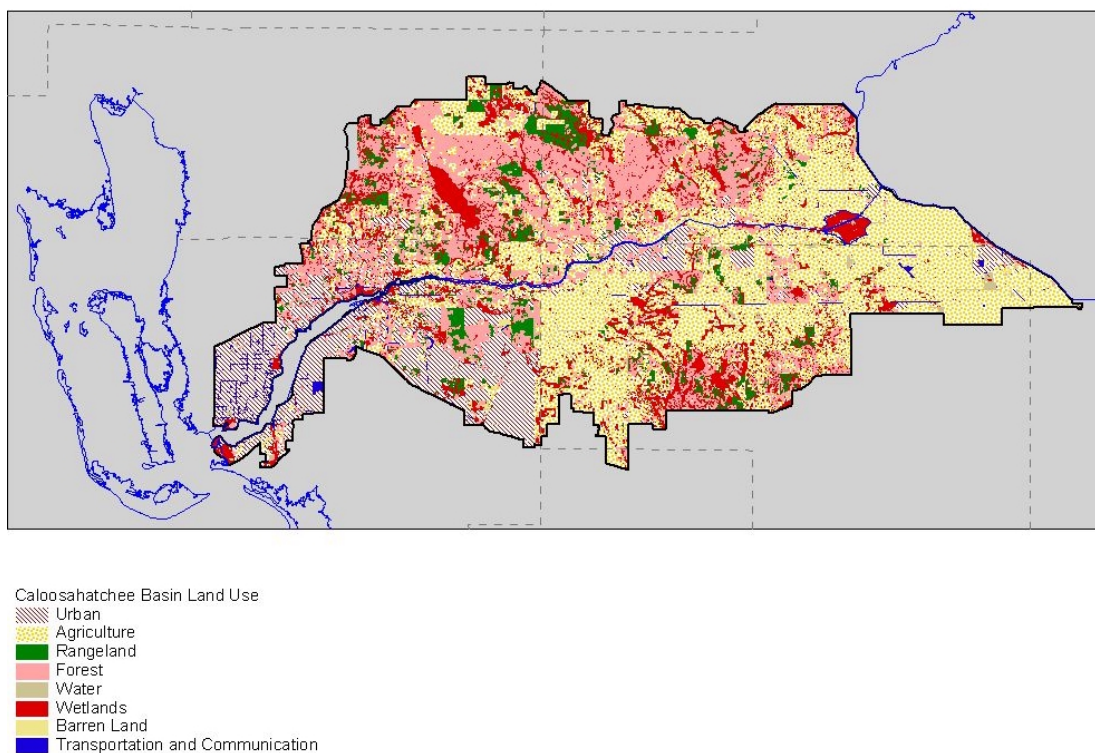
Following dredging of the C-43 Canal, several private, water control districts (WCDs) were established to provide drainage in the basin. These WCDs include those developed for both agricultural and urban land. All of the land on the south side of C-43, excepting urban land immediately adjacent to it, is in one of several WCDs. These districts have constructed drainage canals, water level controls to control drainage, and in many cases, pumps to provide irrigation water for agriculture.

West of LaBelle, WCDs manage water on land away from C-43 but not immediately adjacent to the canal. This has produced a situation where several large drainage canals discharge into small native streams causing flows that exceed the conveyance capacity of those streams and result in severe floods. This was observed following high rainfall in the summer of 1995. The land has been overdrained to permit

development and few storm water detention/retention areas have been constructed to reduce downstream flooding.

LAND USE

Land use in the basin has changed from a mosaic of sloughs, wet prairies, and pine flatwoods to agriculture and urban land (**Figure M-2**). Urban land has developed along the estuary shoreline at Fort Myers and along the river since the 1870s. Less than one percent of the basin was urban in 1950, but urban land now occupies 25 percent of the estuary basin and 8 percent of the total area. There is another 20 percent of the estuary basin that exists as open-urban land. In 1957, urban and agricultural land occupied less than 2 percent of the basin (Mierau et al., 1974). By 1977, agriculture occupied 50 percent of the basin with a compensating reduction in range/scrub land (Fan and Burgess, 1983).

Caloosahatchee Basin Land Use
- Urban
- Agriculture
- Rangeland
- Forest
- Water
- Wetlands
- Barren Land
- Transportation and Communication

Figure M-2. Major Land Use Types in the East Caloosahatchee Basin (ECAL), the West Caloosahatchee Basin (WCAL), and the Direct Caloosahatchee Estuary Basin (Estuary). Land Use for 1955 and 1972 from Mierau et al. (1974). Land Use for 1988 and 1994 from South Florida Water Management District GIS Database (SFWMD,1996).

The eastern portion of the basin was a sawgrass marsh extending from Lake Flirt to Lake Okeechobee with wet prairie to the south and pine flatwoods to the north. This area was subject to prolonged flooding prior to development. Although beef cattle pasturing

has been in southwest Florida for 300 years, intensive agriculture was not a major landuse until large-scale drainage projects were constructed. Citrus production has grown significantly since the 1970s when freezes killed groves in north and central Florida. The areas of citrus and sugar cane are expected to double over the next 15 years (SFWMD, 1994c).

WATER USE

With the increased development in the basin, water use has become a significant issue. Urban Lee County, agriculture, and the environment are the three major water users in the basin (SFWMD, 1994a). Water use demand for 1990 was 94 x 106 m^3 yr^{-1} for the 2-in-10 dry year which is the expected volume of water that would be required two out of every ten years (SFWMD, 1994c). The water supply is limited, particularly during the droughts and the annual dry season. The urban users are located primarily in the lower end of the basin, associated with the cities of Fort Myers, Cape Coral, and urban Lee County. These cities obtain their water from a combination of surface water and ground water, which is recharged from the river. Cape Coral has an independent water supply system that obtains water from the Floridan aquifer, and it has a complete water reuse system. The urban demand is expected to double during the next twenty years (**Table M-1**).

Agriculture uses water for irrigation that supplements local rainfall. The allocation is based on the available water and the crop requirements. Supplemental water replaces a combination of evapotranspiration and seepage losses from the conveyance system. The land owner is allocated ground water or river water to provide supplemental irrigation. Water from Lake Okeechobee is used to provide 94 x 106 m^3 yr^{-1} irrigation water to 135,000 ha: 40 percent of the basin. The most critical needs are in April and May when the evapotranspiration demand is high due to rapid crop growth and the lack of cloud cover.

Native ecosystems are the other major users of water in the basin. Although not explicitly considered in the past, both upland ecosystems and the estuary are important water users. The estuary requires a minimum flow, estimated to be 270 x 106 m^3 yr^{-1}, to avoid hypersaline conditions that are detrimental to juvenile fish and other organisms (Chamberlain et al. 1997). Daily discharge should be in the range of 8.5 to 23 m^{3}s^{-1} (300-800 cfs). Discharge should never exceed 70 m^{3}s^{-1} (2,500 cfs). Wetlands, both sloughs and isolated wetlands, also require the appropriate hydroperiod to remain viable wetland habitats (Duever, 1988).

DISCHARGE AND RUNOFF

There are four sources of discharge to the Caloosahatchee Estuary: Lake Okeechobee, the EAA, the Caloosahatchee River Basin and the Caloosahatchee Estuary Basin. Excess runoff water from the EAA drains into the Caloosahatchee Canal through the S-235 Structure near the lake (**Figure M-1**) and through two privately owned

structures at Lake Hicpochee. Although this storm water runoff normally drains south into the Everglades or is backpumped into Lake Okeechobee, the water can drain into the Caloosahatchee Basin if water levels are high.

The primary source of water to the estuary comes from the river basin. The river drains 344,000 ha, divided into the East Caloosahatchee Basin (ECAL) that drains to the canal between the Moore Haven Lock and spillway (S-77) and the Ortona Lock and Spillway (S-78), and the West Caloosahatchee Basin (WCAL) that drains to the canal between Ortona and the Franklin lock and dam structure (S-79) (**Figure M-1**). Runoff from WCAL is slightly higher than runoff from ECAL (**Table M-1**) indicating the greater flow attenuation in ECAL due to the flatness and thick, sandy soils (Fan and Burgess, 1983). Average annual discharge is presented as the median value rather than the mean, because the annual discharge is log-normally distributed, and the median is a better estimator of the central tendency (**Table M-1**). The extreme values for discharge are given as the 2-in-10 year values for both dry years and wet years. These values are more useful than minimum and maximum values; they provide the values that could be expected two years out of ten years. This is a level of risk that is often used in water resources analysis (SFWMD, 1994b). Surface water inflow from Caloosahatchee River tributaries delivers 53 percent of the river flow, while the remaining flow comes from ground water seepage. There is a high variability in annual runoff volume reflecting the high variability in rainfall.

The Caloosahatchee Canal receives discharge from Lake Okeechobee for flood control and water supply. Regulatory discharge via C-43 (**Table M-1**), to lower lake stage for flood protection, is 37 percent of total surface water discharge from Lake Okeechobee (Fan and Burgess, 1983). In wet years this has resulted in discharge as great as the total runoff from the basin. This excessive discharge primarily from Lake Okeechobee, which is typically concentrated over a few months during the dry season, has had a detrimental impact on the health of the estuary (Chamberlain and Doering, 1997). Water is also released to control algae blooms in the river (Miller et al., 1982). At low flow, algae blooms develop in the canal between S-78 and S-79, producing poor drinking water quality for Fort Myers and Lee County water supplies. Water is released from the lake to flush this water out of the river. Water also is released to push salt water out of the river section that has entered through the locks. This salinity approaches federal drinking water standards at the fresh water intakes. However, flushing of the river reach is generally ineffective (Boggess, 1972).

The estuary also receives runoff from the basin adjacent to the estuary with approximately one-third of the basin discharges to the estuary downstream of S-79. This includes Telegraph Swamp, a portion of Orange River, several small streams along the estuary, and drainage ditch runoff from urban Lee County. Discharge from urban Lee County drains into the estuary through several ditches where runoff is controlled by discharge structures (Johnson Eng., 1992). There are no published data on runoff from the urban portion of the basin.

DISCUSSION

Determining the native, predevelopment annual runoff for the basin is difficult. Determining the predevelopment runoff is difficult because the basin has been substantially altered by development, ditching, and dredging. Flow records prior to construction of C-43 are not available, and it is not possible to determine what were native runoff rates. However, in comparison to runoff rates from the Myakka and Peace River basins in the northern portion of the Charlotte Harbor region, average annual runoff is 20 percent higher in the Caloosahatchee region (Hammett, 1990). The increased runoff indicates one probable impact of canal construction.

In 1994, SFWMD completed the Lower West Coast Water Supply Plan that proposed a strategy for ground water management in the Caloosahatchee Basin (SFWMD, 1994a). Based on the large component of unmet future water supply needs, it was recommended that several steps should be taken to increase water supply. This included development of new sources, in particular, deep ground water and water reuse for the urban area. The new water sources would be supported by development of additional storage, such as aquifer storage and recovery systems and storage in the Caloosahatchee Basin. These facilities may include reservoirs, on-farm retention, and underground storage. The water supply plan pointed out the need to improve the efficiency of irrigation systems. The plan indicated that it would be necessary to develop improved planning and regulatory strategies for minimum flows and levels to protect wetlands and the downstream estuary.

The SFWMD is developing a regional water supply plan for the lower east coast of Florida that includes allocation of water from Lake Okeechobee (SFWMD, 1997). This plan evaluates the surface water issues related to the Caloosahatchee Basin. Water from Lake Okeechobee is used for public water supply and agriculture. With increased urban and agricultural growth in south Florida coupled with the requirement of additional flow from the lake to the Everglades, there will be less water available from Lake Okeechobee for water supply, and it is likely that regulatory discharges will decrease. In normal years, runoff may be sufficient to meet demand, but it likely will be inadequate during drought years (SFWMD, 1997). When water is unavailable from the lake, water users will have to depend on local supplies. The SFWMD is recommending that various storage facilities be developed in the Caloosahatchee Basin to capture runoff and retained regulatory releases from the lake. These facilities, most likely surface water reservoirs, would satisfy unmet water supply needs and modulate discharge to the estuary. Water storage facilities in the Caloosahatchee Basin would reduce the demand for lake water and allow more flexibility for other water users.

SUMMARY

Water use and runoff in the Caloosahatchee Estuary Basin have been substantially affected by anthropogenic activities during the past 100 years. Construction of the C-43 Canal has had the greatest impact on the system, changing the sinuous, shallow river with an extensive flood plain into a large canal and connecting the Caloosahatchee River to

Lake Okeechobee. Construction of the canal has allowed extensive drainage of the basin promoting development of agriculture, primarily citrus and pasture. Excessive drainage during the summer wet season and rapid conveyance in the canal has produced discharge to the estuary causing damage to the habitat. There is also some evidence that overdrainage has occurred, potentially harming upland and wetland habitats in the basin. Construction of the canal has provided the opportunity for agriculture and urban water users to obtain supplemental water from Lake Okeechobee. In the past, water from the lake has been available in most years, but has not been available during droughts when the water level in the lake is too low for discharge or is required by other users. In the future, it is likely that there will be additional urban and agricultural development in the basin. It is unlikely that there will be additional water available from Lake Okeechobee, as the water supply needs of the lower east coast of Florida and the Everglades place greater demand on the water resources (SFWMD, 1997). To meet the consumptive use needs, it will probably be necessary to build water storage facilities in the basin, promote greater water use efficiency, develop additional water supply sources and promote greater water reuse.

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